MADREAN ARCHIPELAGO
RAPID ECOREGIONAL ASSESSMENT

PRE-ASSESSMENT REPORT

REA Pre-Assessment Report for

U.S. Department of the Interior
Bureau of Land Management
Rapid Ecoregional Assessments

November 2013

It is the mission of the Bureau of Land Management to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.

SUBMITTED TO

David Wood, Ecoregional Assessment Project Manager
Department of the Interior
Bureau of Land Management
Building 50, Denver Federal Center
P.O. Box 25047
Denver, CO 80225-0047

SUBMITTED BY

NatureServe
4600 North Fairfax Drive, 7th Floor
Arlington, VA 22203

COVER PHOTO

Near Elgin and Audubon Research Ranch
Tahnee Robertson, Southwest Decision Resources

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Final Madrean Archipelago Ecoregion Pre-Assessment Report

Final Pre-Assessment Report for:
Department of the Interior
Bureau of Land Management
Rapid Ecoregional Assessments

Version Date: 21 November 2013

Submitted to:
David Wood, Natural Resources Project Manager
Department of the Interior
Bureau of Land Management, National Operations Center, BC-662
Building 50, Denver Federal Center
P.O. Box 25047
Denver, CO 80225-0047

Submitted by:
NatureServe
4600 North Fairfax Dr., 7th Floor
Arlington, VA 22203

Patrick Crist, Patrick Comer, Co-Principal Investigators

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Rapid Ecoregional Assessments: Purpose and Scope

Working with agency partners, the Bureau of Land Management began conducting rapid ecoregional assessments (REAs) in 2010 covering approximately 450 million acres of public and non-public lands of the American West. The goal of the REAs is to characterize ecological resources, their status, and their potential for change across the landscape, so that the relative value of and risks facing natural resources can be used to identify potential areas for conservation, restoration, and development. REAs are intended to serve BLM's developing "Ecoregional Direction" that links REAs and the BLM's Resource Management Plans and other on-the-ground decision-making processes. Ecoregional Direction establishes a regional roadmap for reviewing and potentially updating Resource Management Plans, developing multi-year work for identified priority conservation, restoration and development areas, designing regional adaptation and mitigation strategies, and developing conservation land acquisitions. While REAs produce information designed to inform specific management processes, they are not decision documents and stop short of recommending particular management actions.

Pre-Assessment: Purpose and Process

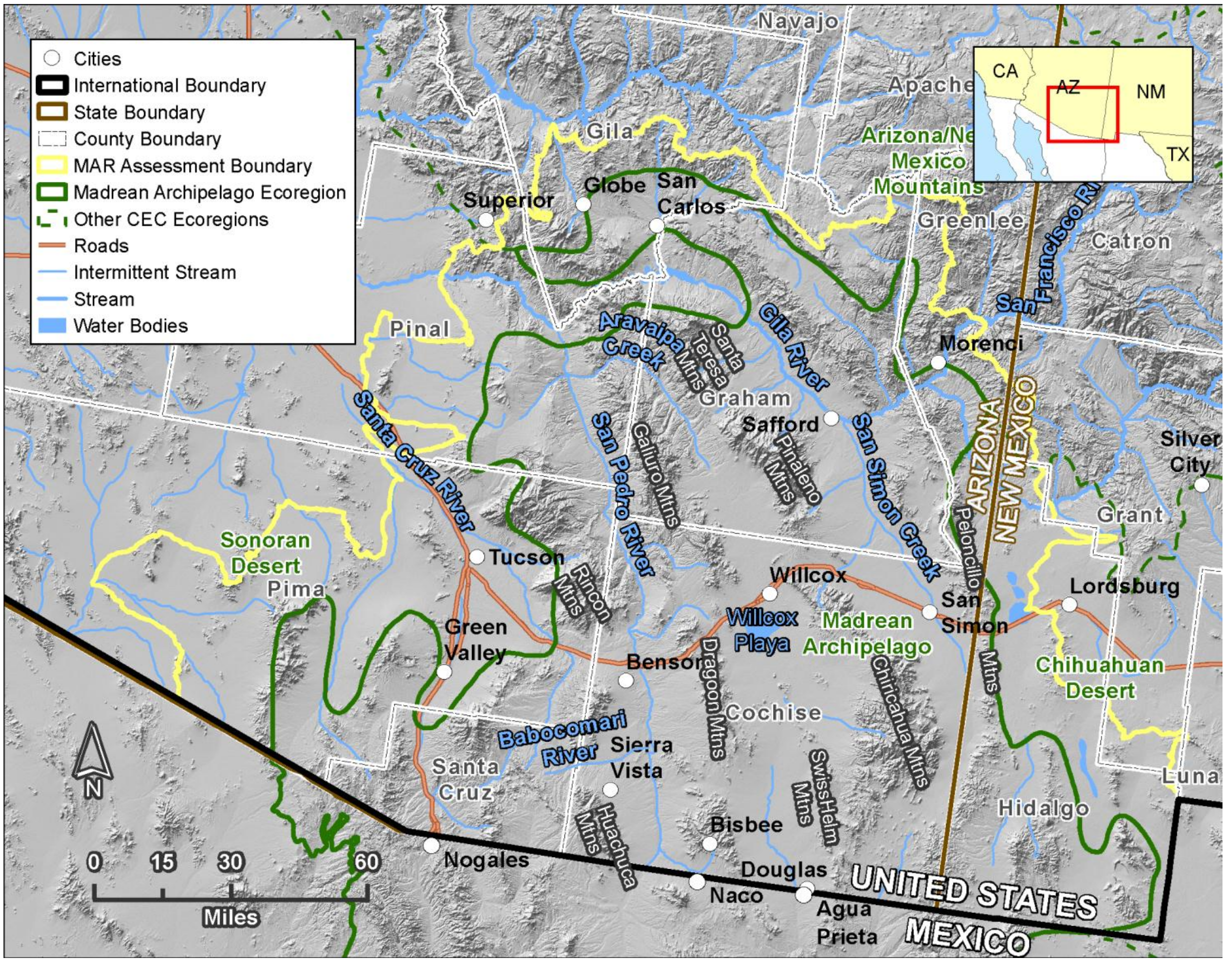
The pre-assessment phase is the first of two phases for an REA. The overall goal of the pre-assessment phase is to lay the foundation for the assessment phase of the REA by identifying the conservation elements (CEs), change agents (CAs), and management questions (MQs) that will be the focus of the REA.

To understand the character of the Madrean Archipelago (MAR) ecoregion in the U.S. and the issues it faces, and to identify the conservation elements, management questions, and change agents for this REA, the contracting team undertook a scoping process that included a series of workshops with experts in the ecoregion, review of relevant literature, and consultation with agency staff and other experts. The pre-assessment report summarizes the conservation elements, management questions, and change agents that were identified, as well as the characterization of the ecoregion as a whole and the natural resource management issues facing it today.

Overview of the Madrean Archipelago Ecoregion

The Madrean Archipelago ecoregion spans approximately 18.5 million acres (7.5 million hectares) and portions of four states in two countries: Arizona and New Mexico in the United States, and Sonora and Chihuahua in Mexico. The REA assessment area is composed of the U.S. portion of the ecoregion, plus the intersecting watersheds, as shown in Figure 1-1; the assessment area encompasses approximately 15.7 million acres (6.4 million hectares).

Figure 1-1. Map of the Madrean Archipelago REA assessment area. The area to be assessed for this REA is the U.S. portion of the Madrean Archipelago **plus** its intersecting 5th-level watersheds, shown in the yellow outline and by the border between the U.S. and Mexico. The Madrean Archipelago ecoregion is shown by the solid, green line and extends into Mexico beyond the map extent.



This ecoregion is characterized by its archipelago of “sky islands” surrounded by “desert seas” – isolated mountain ranges surrounded by extensive, relatively flat valleys of semi-desert grassland and scrubland. Including those located in the Mexico portion of the ecoregion, over 40 mountain ranges are found here, reaching elevations over 8,900 ft (2,715 m) with the highest point of 10,717 ft (3,267 m) at Mt Graham in Arizona. In contrast, the grasslands and semi-desert scrub of the ecoregion generally range in elevation from 2,620 to 4,590 feet (800 to 1,400 m).

These sky islands and desert seas of the southwestern United States and northern Mexico are globally unique. The complex of basins and ranges extends from subtropical to temperate latitudes, hosting species from the Sierra Madre of Mexico and the Rocky Mountains of the United States (Warshall 1995), as well as species and biotic communities characteristic of the Chihuahuan and Sonoran Deserts (Mau-Crimmins et al. 2005). The basin and range topography, diversity of soils, and the arid, monsoonal climate, are the physical drivers shaping this biological diversity. Hydrology, fire, nutrient cycling, herbivory, and insect and disease outbreaks are the natural ecosystem processes shaping the biota of this ecoregion. The Madrean Archipelago is noteworthy for its high level of biological diversity, which results from the confluence of these major biogeographic regions and diversity of topography.

The climate is hot and dry, with an annual average temperature of approximately 61.6° F (16.4° C) and average annual precipitation of approximately 14.7 inches (373 mm). Air temperatures and precipitation have strong seasonality – a cool winter wet season (November-March), a dry season spanning the spring and early summer (April-June), and a hot wet monsoon season from late summer into the fall (July-October), with heavy, short-duration, convective thunder storms and the occasional tropical storm (Serrat-Capdevila et al. 2007). While the majority of the total annual rainfall occurs during the monsoon, between July and October, the second wet season in the winter creates a bimodal distribution of precipitation.

Major rivers in the ecoregion are the westward-flowing Gila and its southern tributaries, the San Pedro River and Santa Cruz River. Other tributaries include the San Francisco and San Simon Rivers, and Aravaipa Creek and Babocomari River, tributaries to the San Pedro River. The ecoregion also includes several playas (closed basins): the Willcox Playa in Arizona and the Animas and Lordsburg playas in New Mexico. Streams throughout the ecoregion have interrupted perennial and intermittent reaches. Dry washes sustain surface flow during and immediately following precipitation events from both rainfall and snowmelt runoff. The types of storms associated with different seasons and weather patterns produce different runoff flow magnitudes and durations.

The biotic communities found along the Madrean Archipelago ecoregion’s gradients include subtropical desert (at the lowest elevations), subtropical thornscrub, semi-desert grasslands, oak savanna, oak-pine woodlands, and mixed conifer forests (Marshall 1957, Mau-Crimmins et al. 2005, Warshall 1995). Interspersed in a mosaic with these upland communities are wetlands characteristic of this region: marshes or ciénegas, ephemerally flooded playa lakes, and floodplains along montane and lowland streams and rivers with gallery forests of deciduous trees and shrubs.

Many plant and animal species are at the edges of their ranges in this region, particularly southern species of trees, orchids, moths, birds, and bats which reach the northern limit of their range in the region (Felger and Wilson 1995). The region is also home to a high number of endemic and threatened and endangered species (Warshall 1995). Over 4,000 vascular plant species are documented in this ecoregion. Of the 468 species of birds documented in southeastern Arizona in the past 50 years, 207 species are known or thought to breed here, along with 246 butterfly and skipper species, and hundreds of species of wood-rotting fungi (Bailowitz and Brock 1991, Corman and Wise-Gervais 2005, Edison et al. 1995, Gilbertson and Bigelow 1998, Marshall et al. 2004). The region is notable for supporting 15 species of hummingbirds and 21 species of sparrows that are either winter or permanent residents (Bodner et al. 2006) Southeastern Arizona has the greatest mammalian diversity north of Mexico (Turner et al. 1995) and twice the mammal diversity of Yellowstone National Park. The 110 mammal species documented in the Madrean Archipelago ecoregion includes a high diversity of bat species (23), a variety of narrowly endemic species such as the white-sided jackrabbit (*Lepus callotis*), the Arizona cotton rat (*Sigmodon arizonae*), the Mearn's pocket gopher (*Thomomys bottae mearnsi*), and species at the edges of their ranges such as jaguar (*Panthera onca*) and ocelot (*Leopardus pardalis*) (Felger et al. 1997, Schmidt and Dalton 1995, Simpson 1964). Large mammals with extensive geographic ranges inhabiting this ecoregion include black bear (*Ursus americanus*), mountain lion (*Puma concolor*), bighorn sheep (*Ovis canadensis*), and pronghorn (*Antilocapra americana*).

Conservation Elements

The process of identifying CEs for this REA was a key initial task that took place over several months through a process of reviewing and compiling relevant assessments and information on CEs, applying selection criteria, and engaging REA participants to obtain expert review and judgment to arrive at a final list. Representing the biota of an ecoregion with a small number of CEs is challenging; for this REA, criteria developed by BLM were applied that sought to provide broad geographic coverage of the ecoregion through strategic selection of ecological system types. These were then supplemented with landscape species representative of other environments that were not adequately reflected by the ecological system types, or that spanned ecological system types, or were otherwise of management concern. AMT workshops and a separate series of scoping workshops were critical venues for input and discussion around CE selection.

Eighteen conservation elements were selected to be the focus of this REA: ten ecological systems, six species, and two species assemblages. NatureServe's ecological systems are defined as groups of plant communities that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients (Comer et al. 2003); some of the CEs are combinations of two or more NatureServe ecological systems. Selected ecological systems are listed in Table 1-1, and species are listed in Table 1-2.

The Apacherian-Chihuahuan Mesquite Upland Scrub system, which occupies close to 20% of the ecoregion, was also considered as a system CE. However, questions identified for this type during the development forums and subsequent discussions differed from the ecological status-related questions identified for all of the other CEs; instead, questions centered on issues tied to the restoration of this type to the semi-desert grassland ecological system into which it has encroached. Therefore, it was selected as a unique element for assessment in the REA.

Table 1-1. Ecological system conservation elements (CEs) selected for the Madrean Archipelago REA. The ecological systems are organized in this table according to the four major system divisions or groupings (valley upland system, montane upland system, connected stream and wetland, and isolated wetland) of the ecoregion conceptual model. Percent of ecoregion occupied by each system is calculated for the U.S. portion only.

Ecological System Name	Approx. % Ecoregion
Valley Upland System Division	**56.0%**
Chihuahuan Creosotebush Desert Scrub	13.2%
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	18.2%
Madrean Encinal	5.1%
Montane Upland System Division	**13.4%**
Madrean Pinyon-Juniper Woodland	5.8%
Montane Conifer-Oak Forest and Woodland	2.8%
Mogollon Chaparral	4.8%
Isolated Wetland System Division	**<1%**
North American Warm Desert Playa and Ephemeral Lake	<1%
Connected Stream and Wetland System Division	**4.3%**
North American Warm Desert Riparian Woodland and Shrubland, Mesquite Bosque and Stream	3.3%
North American Arid West Emergent Marsh/Ciénega and Pond	1.0%
North American Warm Desert Lower Montane Riparian Woodland and Shrubland and Stream	<1%

Table 1-2. Species conservation elements (CEs) selected for the Madrean Archipelago REA.

Category	Species Common Name	Scientific Name
Mammal	Desert bighorn sheep, all subspecies	*Ovis canadensis*
Mammal	Pronghorn	*Antilocarpa americana*
Mammal	Coues deer	*Odocoilus virginianus couesi*
Mammal	Black-tailed prairie dog	*Cynomys ludovicianus*
Mammal	Nectar-feeding bat assemblage	NA
Bird	Grassland bird assemblage	NA
Reptile	Ornate box turtle	*Terrapene ornata luteola*
Amphibian	Chiricahua leopard frog	*Lithobates chiricahuensis*

Current Issues and Agents of Change

Land managers face numerous challenges for managing natural resources as a result of the interplay between human activities and indirect influences and the physical and ecological processes shaping the Madrean Archipelago ecoregion. The major landscape change agents and issues in the MAR include the following:

- Climate change
- Water availability
- Altered fire regimes and fire suppression
- Invasive, non-native species
- Encroachment of native woody species
- Livestock grazing
- Development (residential, industrial, utilities, etc.)
- Border control activities and infrastructure
- Agriculture

A number of studies have reviewed and analyzed the impacts climate change will have on weather patterns and ecosystems within the southwestern United States, including the Madrean Archipelago. Several climate models predict the region will experience a warmer and drier climate over the 21st century, and evidence suggests that recent events are signs that climate change is already on track with these predictions (Dominguez et al. 2009, Heinz Center 2011b, IPCC 2007, Seager et al. 2007, USGCRP 2009). Projected direct impacts of the warmer, drier climate include increased intensity and frequency of drought, increased flooding, and reduced water availability. Climate alterations interact with other stressors such as altered fire regimes and invasive species, often producing feedback loops that intensify and further the effects of one or more stressors. Climate change and its interactions with other processes and influences is expected to have substantial impacts on the ecosystems and species of this ecoregion.

Water availability is an on-going, overarching challenge permeating all aspects of life in this ecoregion. The primary anthropogenic water uses include irrigation for agricultural crops, municipal water supplies, industrial uses (primarily mining), and livestock. Groundwater is the primary source for cultural water uses. In the context of natural resource management in this ecoregion, the overriding concern around water is the increasing demand on a shrinking supply, and the associated on-going impacts on aquatic ecosystems and wildlife as a whole.

A variety of invasive, non-native species are present in this ecoregion, including species such as buffelgrass (*Pennisetum ciliare*), Lehmann's lovegrass (*Eragrostis lehmanniana*), American bullfrog (*Lithobates catesbeiana*), northern crayfish (*Orconectes virilis*), tamarisk (*Tamarix* spp.), and many others. The most serious impact of the introduction of an invasive non-native species is the conversion of one biotic community to another – e.g., conversion of a grassland to a shrubland. Non-natives may also cause extensive displacement or reduction in diversity of native species – e.g., native grasslands becoming dominated by Lehmann's lovegrass (*Eragrostis lehmanniana*).

The two native mesquite species, honey and velvet mesquites (*Prosopis glandulosa* var. *torreyana* and *P. velutina*) have been expanding their distribution and dominance in semi-desert grassland over the last 130 years. Increases of mesquite in semi-desert grassland in the MAR ecoregion are related to historical grazing impacts (Milchunas 2006), climate patterns (Curtin 2002), groundwater pumping, prairie dog removal (Weltzin et al. 1997), and potentially interactions of current grazing with other factors (Milchunas 2006). Over 70% of historical and current grasslands are estimated to be shrub-encroached, and 36% of grasslands are estimated to be type converted to shrubland (Gori and Enquist 2003).

While fire is a natural ecosystem process, fire regimes have been altered from their historical patterns. Fire suppression starting in the middle of the 20th century resulted in further accumulation of fuels in the region's forests. As a result of on-going fire suppression, exacerbated by climate change, these forests now experience mixed-intensity or stand-replacing fires rather than the historical low-intensity fires. High-intensity fire can have catastrophic effects including erosion, loss of seed sources for natural regeneration of tree species, wildlife habitat loss, a breakdown in the proper functioning of ecosystems, and reduced future site productivity.

Livestock grazing is the most widespread land use in this ecoregion. Impacts from present-day livestock grazing are variable, and often synergistic with factors including climate patterns (droughts, precipitation quantity and timing), past grazing history, fire, and other herbivores (e.g., prairie dogs). Depending on the intensity, past history, and other site-specific factors, and interactions with climate patterns, fire, and other ecological processes, present-day grazing has the potential to degrade or alter ecosystems in this region.

The effects of urban, suburban, and exurban infrastructure and other direct anthropogenic land uses are also of concern from a biodiversity management perspective. The footprint of urban areas or other municipalities, transportation corridors, border-related infrastructure (barriers, roads, lighting, etc.), energy-related development, mines, and agriculture have caused the direct loss of habitat and ecosystems, and expansion of these features will result in further losses and degradation. To varying degrees, these footprints also create impediments to species movement and dispersal across the landscape or otherwise fragment habitat; border-related fencing is of particular concern. They may also alter hydrologic regimes, depending on where and how they are constructed. In addition to the footprint, mining may also result in water quality and soil contamination issues. As noted above, water withdrawals associated with municipalities, agriculture, and mining are contributing to significant changes in groundwater and aquatic ecosystems.

From Management Questions to REA Assessments

The management issues that were identified in this ecoregion, such as water availability, climate change, and fire, have broad commonalities. For all of the identified change agents, there is a need to better understand how they affect the condition (or ecological status) of ecosystem and species CEs, where those effects are occurring, where they may occur in the future, and how the change agents may alter the condition or status of CEs in the future. In addition, there is a need to understand the interactions and synergies among the change agents, and how those synergies may further affect the ecosystem and species CEs. These management information needs can be further distilled into the following broad and inter-related categories of management questions:

- What is the current condition or ecological status of ecosystem and species conservation elements?
- Where do change agents and their effects overlap geographically with conservation elements? Where will they overlap in the foreseeable future?
- How might the conservation elements be affected by change agents in the foreseeable future?

The individual management questions around the issues facing natural resources managers and the corresponding broad categories of management information needs form the foundation for identifying the assessments that will be conducted for the Madrean Archipelago REA.

2 Introduction

2.1 Rapid Ecoregional Assessments: Purpose and Overview

Working with agency partners, the Bureau of Land Management began conducting rapid ecoregional assessments[1] (REAs) in 2010 covering approximately 450 million acres of public and non-public lands of the American West. The goal of the REAs is to characterize the status of ecological resources and their potential for change across the landscape, so that the relative value of and risk facing natural resources can be used to identify potential priority areas for conservation, restoration, and development. REAs are intended to serve BLM's developing "Ecoregional Direction" that links REAs and the BLM's Resource Management Plans and other on-the-ground decision-making processes. Ecoregional Direction establishes a regional roadmap for reviewing and potentially updating Resource Management Plans, developing multi-year work for identified priority conservation, restoration and development areas, designing regional adaptation and mitigation strategies, and developing conservation land acquisitions. While REAs produce information designed to inform specific management processes, they are not decision documents and stop short of recommending particular management actions.

REAs are designed around ***management questions (MQs)*** that specify the key information needs of managers as expressed by the Assessment Management Team (AMT). REAs describe and map ***conservation elements (CEs)***, which are generally ecosystems, species, or other natural features of high ecological value or sensitivity. REAs look across all lands in an ecoregion to identify regionally important habitats for fish, wildlife, species of concern, and other features of management interest. REAs then evaluate the potential impacts on CEs from four overarching categories of environmental ***change agents (CAs):*** climate change, fire, invasive species, and development (such as land use, energy development, infrastructure, or hydrologic alterations).

REAs address all lands within the ecoregion of interest, regardless of ownership. Therefore, BLM engages with partners and stakeholders within the ecoregion to obtain input and to provide a set of products that can be used by any interested agency or organization. REAs are conducted by contractors, with guidance and input from BLM and partners within the ecoregion; BLM provides oversight for the project. The Assessment Management Team (AMT) and the Technical Team, which are composed of

[1] Also see BLM's REA website at www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html.

decision makers and technical experts from state and federal agencies, provide guidance and input throughout the REA process.

The REA for the Madrean Archipelago (MAR) ecoregion is scheduled to be completed within a two-year period; more information on project schedule and timing is provided in the assessment work plan (Harkness et al. 2013). (For more information on the structure of the various BLM- and contractor-led teams conducting this REA, the reader is referenced to the pre-assessment work plan (Crist et al. 2013) for this REA, available at http://www.blm.gov/pgdata/etc/medialib/blm/wo/Communications_Directorate/public_affairs/landscape_approach/documents1.Par.26493.File.dat/MAR-1_Pre-assessment_Work_Plan.pdf)

2.2 Purpose, Organization, and Content of the Pre-Assessment Report

The REA process is organized as a series of tasks in two major phases: Phase 1, the pre-assessment phase, and Phase 2, the assessment phase. The overall goal of the pre-assessment phase is to lay the foundation for the assessment phase of the REA. During this first phase, the ecoregion's physical characteristics and processes, its biodiversity and associated processes, its anthropogenic context, and the interactions and relationships among these are characterized in order to understand the ecoregion as a whole. In addition, the management questions (MQs) of concern in the ecoregion, and the conservation elements (CEs) and change agents (CAs) associated with these management information needs, are identified and summarized. The MQs, CEs, and CAs will be assessed in Phase 2, the assessment phase. Table 2-1 provides a simple summary of the two phases and the major tasks comprising an REA; an outline of the specific components of each task is included in the work plan developed for this REA (see documents posted at http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/madrean.html#memo).

Table 2-1. Overview of Phases and Tasks in the REA process.

Phase	Task #	Task
Phase 1: Pre-Assessment	**Task 1**	**Initiate REA Project**: • Engage Teams and Develop Pre-Assessment Work Plan
	Task 2	**Implement Pre-Assessment Work Plan**: • Characterize the Ecoregion • Identify MQs, CEs, and CAs • Develop Conceptual Models (CMs) for CEs • Summarize in Pre-Assessment Report
Phase 2: Assessment	**Task 1**	**Create Assessment Work Plan**
	Task 2	**Obtain Data and Develop Models for How to Conduct the Assessments**: • Inventory, Acquire, and Evaluate Data • Develop Process Models
	Task 3	**Develop Geoprocessing Models and Conduct the Assessments**: • Develop Geoprocessing Models • Conduct Analyses • Generate Findings • Assemble Data Packages
	Task 4	**Final REA Report**: • Summarize Assessment Findings and Their Applications

The pre-assessment report is the culmination of the first phase of the REA; its primary purpose is to serve as a stand-alone document that characterizes the ecoregion as a whole, the management information needs, the conservation elements (species and ecological systems), the change agents, and the interactions and relationships among these within the Madrean Archipelago ecoregion. It was drafted by the contracting team over the course of the pre-assessment phase, with multiple reviews by the AMT and associated revisions. Based on current scientific understanding derived from literature review and scoping workshops, the interactions among CEs, CAs, and other components of the environment are described and illustrated through conceptual models for the ecoregion as a whole, and for the selected CEs. The CE conceptual models are a major product of the pre-assessment phase and therefore key components of the pre-assessment report; they form the foundation for the group of CE-based assessments that will be conducted in the second phase of the REA and are provided as appendices to the pre-assessment report. In addition to serving as a stand-alone characterization of the ecoregion, this pre-assessment report will also serve as the foundation for the final report for the Madrean Archipelago REA.

The interactions and relationships between the conservation elements, the change agents, and the human community of this ecoregion form a dense and complex web, with numerous synergistic effects. Addressing one issue inevitably requires reference to other interacting factors. The report structure is intended to reduce redundancy to the extent possible when characterizing such interconnected features and processes. Following this introductory section, the pre-assessment report is organized into these major sections:

- Overview of the Pre-Assessment Process
- Ecoregion Conceptual Model
- Human Context
- Current Issues
- Synthesis of Management Concerns

Following the main body of the report, these additional contents are included:

- Annotated Bibliography
- Literature Cited
- Glossary
- List of Acronyms
- Appendices

Overview of the Pre-Assessment Process

The first section, **Overview of the Pre-Assessment Process**, is intended to briefly document the process and methods used to conduct the pre-assessment. Although it focuses on methods (rather than results), the final list of **conservation elements** that were selected for assessment in this REA is provided in this section.

All subsequent sections in this report can be thought of as the results or findings of the pre-assessment.

Ecoregion Conceptual Model

The second section, **Ecoregion Conceptual Model**, summarizes the ecoregion's physical characteristics and processes, and its biodiversity and associated processes. Here, the intent is primarily to characterize the "natural" or "acceptable" functioning of these driving processes, without reference to anthropogenic impacts on them. It provides the framework for looking at ecological integrity as a whole, across the ecoregion, as well as the context for the **conservation elements** selected for the REA.

Human Context

People and their activities and influences in relation to the natural resources of the ecoregion are a key component of the ecoregion conceptual model as well as the foundation for the **Current Issues**. A brief overview of the **Human Context** of this ecoregion, including land ownership patterns and land uses, is therefore placed in its own section as the bridge between the **Ecoregion Conceptual Model** and **Current Issues**.

Current Issues

The fourth section, **Current Issues**, describe challenges facing the ecoregion as a whole, focusing on those issues that are of particular concern to natural resource managers. The effects of the land uses summarized in the Human Context section are described here. Numerous other issues besides land uses, such as climate change, water availability, and fire, are addressed as well. Although summarized in more specific groupings, the issues of concern to resource managers in this ecoregion reflect the four broad categories of change agents that are being assessed in this REA: climate change, fire, invasives, and development. Thus the **change agents** and management information needs or **management questions** are embedded in this section.

Many of the features and processes that shape the ecoregion and helped define the **Ecoregion Conceptual Model** are reflected in the **Current Issues** chapter as well – for example, climate change, hydrology, and fire. Although this may result in a little redundancy, there are two distinct purposes for these chapters. As noted above, the **Ecoregion Conceptual Model** simply characterizes the "natural" or "acceptable" functioning of these driving processes. The **Current Issues** section focuses on how these processes or ecosystems may be functioning outside their "acceptable" range as a direct or indirect consequence of human activities, and the associated effects on natural resources. This provides a catalog of issues facing natural resource managers in this ecoregion; understanding these key issues informs the kinds of questions the REA should address.

Synthesis of Management Concerns

The last section in the main report is the **Synthesis of Management Concerns**. Based on the review of **management questions** and current issues in the ecoregion as summarized in the **Current Issues** chapter, this brief section provides a broad overview of the major groups of questions that can potentially be addressed in this REA; this section in part sets the stage for developing the work plan outlining how the assessments will be conducted in Phase 2 of the REA.

Appendices

A series of appendices are also included with the pre-assessment report:

- **Appendix A: Detailed Methodology and Rationale:** This appendix complements the brief summary of pre-assessment methods contained in the **Overview of the Pre-Assessment Process** section by providing additional detail on the methods and approaches used in the pre-assessment phase
- **Appendix B: Management Questions:** This appendix contains the original set of management questions identified through scoping workshops and other means. This detailed list of questions helped inform the set of assessments that are under consideration for conducting in the second phase of the REA. The original management questions are included here for reference, so that readers may have a more detailed picture of the type and range of information needs identified by natural resources managers working in this ecoregion and participating in this REA.
- **Appendices C, D, and E: Conceptual Models for Conservation Elements** and the novel Mesquite Upland Scrub: This critical appendix contains the CE conceptual models organized into the following groupings:
    - **Appendix C:** Ecological System Conceptual Models
    - **Appendix D:** Species and Species Assemblage Conceptual Models
    - **Appendix E:** Mesquite Upland Scrub Conceptual Model
- **Appendix F: Other Non-Native Species:** Summary information was compiled for a range of invasive non-native species relevant to this ecoregion. Summaries for species that appear to be of greatest concern are included in the main body of the report; this appendix contains summaries for additional species that are of concern, including species or pathogens that are not yet established in the ecoregion, but are particularly problematic and have potential to be introduced and spread.

Other Reference Sections

Readers may also find useful the **Glossary** and **List of Acronyms** provided at the end of the main body of the report.

2.3 Overview of the Madrean Archipelago Ecoregion

The bi-national Madrean Archipelago (MAR) ecoregion is approximately 18.5 million acres (7.5 million hectares) and spans portions of four states in two countries: southeastern Arizona and extreme southwestern New Mexico in the United States, and northeastern Sonora and northwestern Chihuahua in Mexico. As defined for North America by the Commission for Environmental Cooperation[2] (CEC), this ecoregion lies to the immediate east of the Sonoran Desert, to the south of the Arizona/New Mexico Mountains, to the west of the Chihuahuan Desert, and to the north of two ecoregions entirely within Mexico: the Sinaloa and Sonora Hills and Canyons with Xeric Shrub and Low Tropical Deciduous Forest, and the Sierra Madre Occidental with Conifer, Oak, and Mixed Forests (Figure 2-1).

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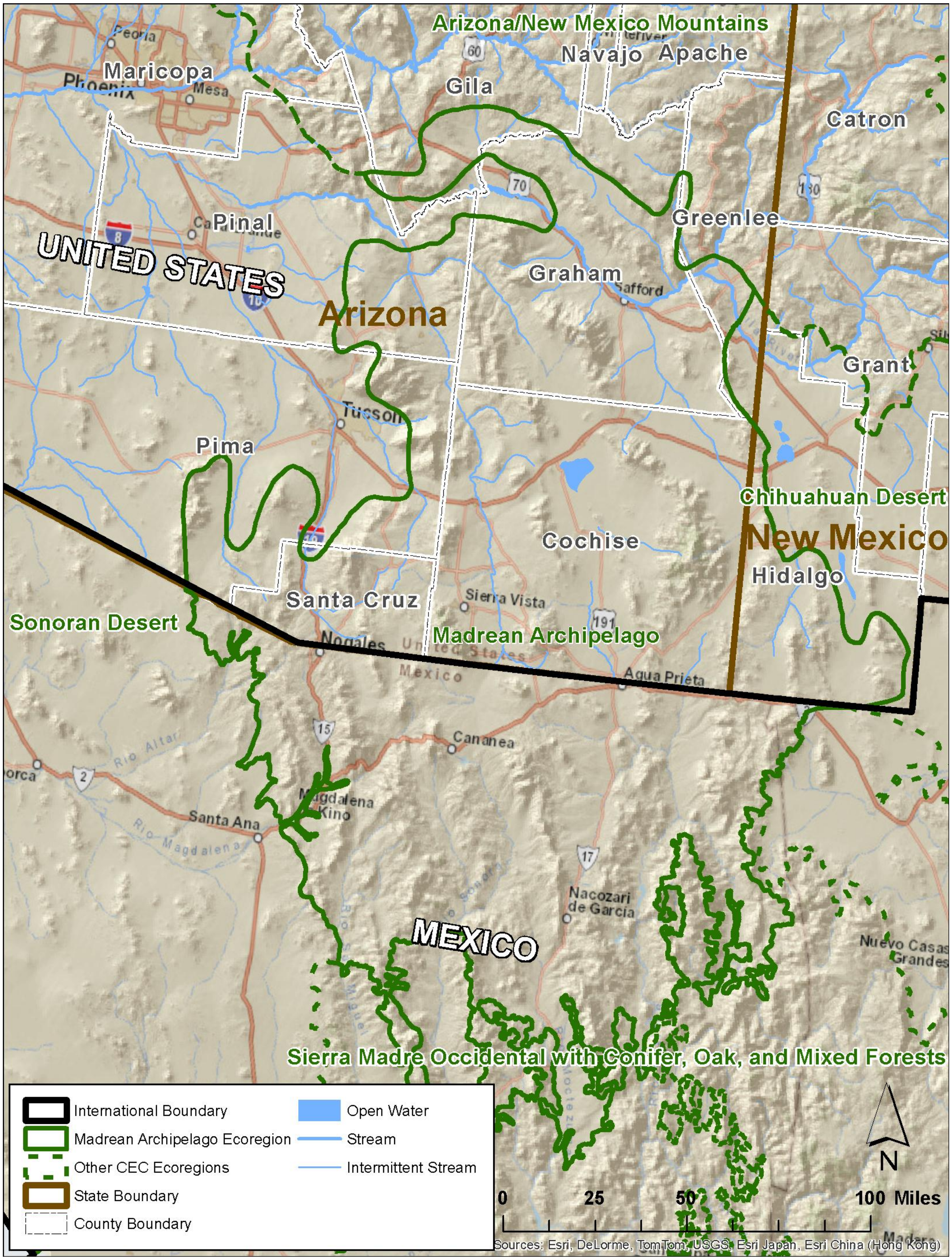
[2]The CEC was established in 1994 by Canada, Mexico, and the United States to implement the North American Agreement on Environmental Cooperation (NAAEC), the environmental side accord to the North American Free Trade Agreement.

The Madrean Archipelago is entirely contained within the Forest Service's Chihuahuan Desert Province and is approximately the western one-third of 32A1-Basin and Range Section (McNab et al. 2007). The Natural Resources Conservation Service (NRCS) places it within the Southeastern Arizona Basin and Range Major Land Resource Area (MLRA) (#41) within the Western Range and Irrigated Region (NRCS 2006). It falls into the North American Warm Desert EcoDivision as defined by NatureServe (Comer et al. 2003). The Apache Highlands ecoregion as defined and used by The Nature Conservancy (Marshall et al. 2004) is somewhat larger than the Madrean Archipelago ecoregion; the Apache Highlands incorporates a large area of the Mogollon Rim to the northwest of the MAR.

This ecoregion is characterized by its unusual physiography, comprised of an archipelago of numerous isolated mountain ranges or "sky islands" surrounded by extensive intervening valleys or "desert seas." The mountain ranges generally trend southeast to northwest. Including those located in the Mexico portion of the ecoregion, over 40 mountain ranges are found here, reaching elevations over 8,900 ft (2,715 m) with the highest point of 10,717 ft (3,267 m) at Mt Graham (NRCS 2006). In contrast, the grasslands and semi-desert scrub occupying the smooth, intervening valleys of the ecoregion generally range in elevation from 2,620 to 4,590 feet (800 to 1,400 m).

These sky islands of the southwestern United States and northern Mexico are globally unique – the complex of basins and ranges extends from subtropical to temperate latitudes, hosting species from the Sierra Madre of Mexico and the Rocky Mountains of the United States (Warshall 1995), along with characteristics of the Chihuahuan and Sonoran Deserts (Mau-Crimmins et al. 2005).The Madrean Archipelago is particularly biologically diverse due to its biogeographic setting between tropical and temperate regions, and to the great diversity of habitats resulting from the elevational gradients (Coblentz and Riitters 2004) coupled with geologic and soil substrate diversity. The biotic communities found along the Madrean Archipelago ecoregion's gradients include subtropical desert (at the lowest elevations), subtropical thornscrub, semi-desert grasslands, oak savanna, deciduous riparian forest, oak-pine woodlands, and mixed conifer forests (Brown 1982, Marshall 1957, Mau-Crimmins et al. 2005, Warshall 1995). Interspersed with these upland communities are a variety of wetlands: marshes or ciénegas, ephemerally flooded playa lakes, and floodplains along mountain or lowland streams and rivers with gallery forests of deciduous trees and shrubs.

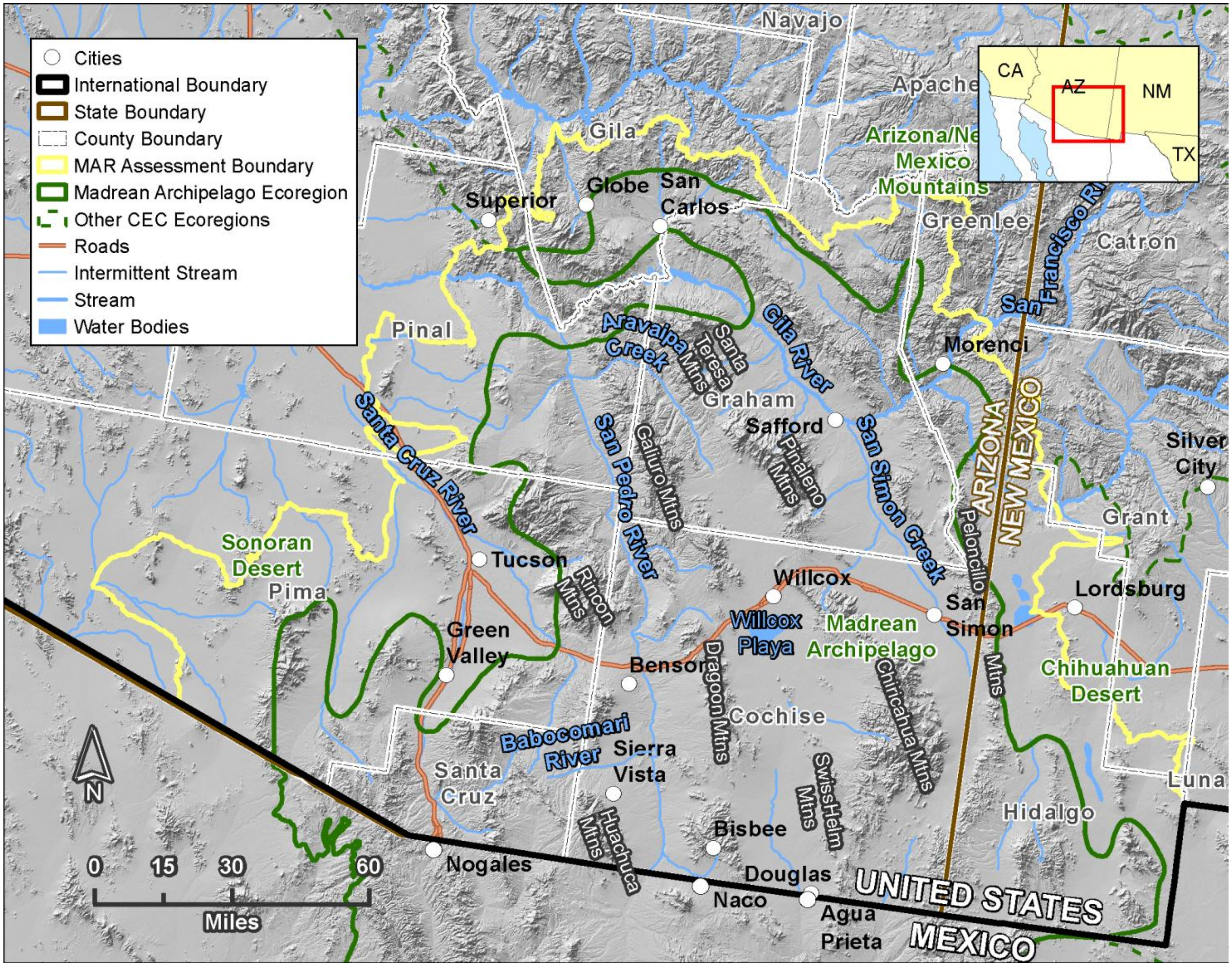
Figure 2-1. Map of the bi-national Madrean Archipelago ecoregion. The boundary of the Madrean Archipelago ecoregion is shown with the solid, dark green line; it is located in southeastern Arizona, southwestern New Mexico in the U.S., and northeastern Sonora and northwestern Chihuahua in Mexico.



2.3.1 Assessment Area for Madrean Archipelago REA

The U.S. portion of the Madrean Archipelago ecoregion is the primary focus of this REA. The conceptual models for the ecoregion and the CEs draw on literature for the entirety of this bi-national ecoregion, as appropriate; for example, the CE conceptual model narratives typically discuss the CE across its range. However, the geospatial analyses in the assessment phase will focus solely on the U.S. portion of the ecoregion. To ensure that influences affecting the periphery of the ecoregion are characterized in the geospatial assessments, the U.S. portion of the ecoregion was buffered with intersecting 5th-level watersheds to define the geographic area that will be assessed in this REA. The REA assessment area (inclusive of the overlapping watersheds) encompasses approximately 15.7 million acres (6.4 million hectares) (Figure 2-2).

Figure 2-2. Map of the Madrean Archipelago REA assessment area. The area to be assessed for this REA is the U.S. portion of the Madrean Archipelago **plus** its intersecting 5th-level watersheds, shown in the yellow outline and by the border between the U.S. and Mexico. The Madrean Archipelago ecoregion is shown by the solid, green line and extends into Mexico beyond the map extent.



3 Overview of the Pre-Assessment Process

To understand the character of the Madrean Archipelago ecoregion in the U.S. and the issues it faces, and to identify the management questions (MQs), conservation elements (CEs), and change agents (CAs) to be addressed in this REA, the contracting team undertook a scoping process that included a series of workshops with experts in the ecoregion, review of relevant literature and publications, and consultation with agency staff and other experts. This section of the report briefly summarizes the approach and methods for conducting the various components of the pre-assessment. A general overview of the entire pre-assessment process is provided here, followed by summaries of the approaches for identifying MQs, CEs, and CAs. More detail on the specifics of these methods is included in **Appendix A**.

An initial REA kick-off workshop was held with the Assessment Management Team (AMT) in December 2012 to engage the AMT and technical team participants and agree on the approach for conducting the pre-assessment. This workshop also resulted in the identification of an initial set of three CEs (two ecological systems and a species) that experts were confident should be addressed in this REA. Given the amount of time and review needed to develop and finalize conceptual models for the full set of selected CEs, these three CEs were identified in advance of the formal CE selection process to permit the contracting team to initiate CE conceptual model development and obtain review on conceptual model content and approach as early in the project as possible.

In January 2013, a series of “Development Forums” – or scoping workshops – were held in BLM offices in Las Cruces, New Mexico and Safford and Tucson, Arizona with land managers, biologists, and other experts (identified by AMT members and BLM staff) from a variety of federal and state agencies. Following an overview of the REA process, participants were asked to identify management issues they viewed as critical, framed as questions that, if answered, could inform decision-making around resource management. Information gathered in these forums and through literature review served to identify a comprehensive initial set of potential MQs, CEs, and CAs. Subsequent smaller phone or web conferences served to further refine and finalize the CEs. Direction and comment from partners participating in the second AMT workshop in April/May 2013 and subsequent discussions with BLM helped to further refine the MQs and CAs.

Literature review was the primary source for developing conceptual models both for the ecoregion as a whole and for the individual CEs; reviewer comments were also a critical input to help refine these. In particular, the conceptual model for the Madrean Archipelago ecoregion as a whole was developed using recommended approaches (e.g., Gross 2005), drawing upon a wealth of existing descriptive information, including conceptual models developed for the National Park Service Inventory and Monitoring programs (Mau-Crimmins et al. 2005), ecoregion descriptions of the NRCS (NRCS 2006) and CEC (Wiken et al. 2011), conference proceedings (Gottfried et al. 2005), and the Apache Highlands Ecoregional Plan of The Nature Conservancy (Marshall et al. 2004). More detail on approaches and methods for developing the ecoregion and CE conceptual models is provided in **Appendix A**.

3.1 Management Questions and REA Assessments: Process for Identification and Synthesis

Management questions are the questions for which information is needed in order to guide natural resource management and land use decisions. They are generally framed around a natural resource (or CE) and one or more CAs or other factors affecting the resource. REAs provide information and analysis results that can help address the MQs. As a result, MQs guide the development of the information, analyses, data, and tools that are created in an REA.

A set of approximately 200 MQs was identified by compiling issues and questions suggested by participants in the series of Development Forums mentioned above. These questions touched on all of the CAs and other human influences, and their relationship to the natural resources of this ecoregion as described in referenced reports. Many of the questions dealt with intertwined and synergistic effects of multiple CAs, including historical CAs whose effects are still being felt today. Because the questions were initially compiled from multiple workshops, there is some redundancy among the original set of questions.

In the REA, MQs help determine what assessments are conducted and what associated data sets and tools are developed. While many of the analyses are likely to directly and fully address many of the identified MQs, not all MQs that have been suggested can be addressed or addressed comprehensively. In addition, the analyses and information generated by the REA can help address many other management-related questions that weren't explicitly identified in the REA process.

The MQs identified in the forums reflect the information needs of participating natural resources managers in the ecoregion. The contracting team compiled and organized the questions and issues thematically, both by change agent (e.g., climate change, fire, grazing, etc.), and by groups of conservation elements (upland systems, wetland systems, wildlife species, etc.). This allowed both the contractor and REA participants to see the patterns in the types of issues that are of greatest concern and should be addressed in the REA. Based on this thematic organization and review, the contracting team distilled the questions into a small, discrete series of management concerns around a particular issue or change agent. These management concerns are framed as a series of questions and are summarized in the relevant sections of the **Current Issues** chapter in this report; for example, for fire-related management issues, see the section **Management Concerns Around Fire**. The questions identified in each of these sets of management concerns form the basis for the assessments proposed for this REA. The assessments proposed for this REA are briefly characterized in the last chapter of this report, **Synthesis of Management Concerns: From Management Questions to Proposed REA Assessments**; the separate work plan (Crist et al. 2013) developed for this REA includes a listing of each of the proposed assessments and a proposed approach for conducting them.

As noted previously, **Appendix A** includes more detail on the process used to identify management questions and issues, and get from the initial set of MQs to the set of assessments reflected in the work plan. **Appendix B** details each of the MQs that were originally identified in the Development Forums.

3.2 Conservation Elements

Conservation elements are one of the core components of the REA. They are the natural resources – such as habitats, ecosystems, and species – or other features that are the focus of the assessment. The identification of conservation elements for this REA was a critical first step that took place over several months through a process of reviewing and compiling relevant assessments and information on potential CEs, applying selection criteria, and engaging REA participants to obtain expert review and judgment to arrive at a final list. Representing the biota of an ecoregion with a small number of CEs is challenging; for this REA, criteria developed by BLM were applied that sought to provide broad geographic coverage of the ecoregion through strategic selection of ecological system types. REA participants attempted to identify a cross-section of ecological systems that are representative of or endemic to this ecoregion, and a suite of complementary and regionally significant species that are representative of other environments that were not adequately reflected by the ecological system types or that span ecological system types. CEs also needed to be of management concern; detailed CE selection criteria are described further below. The AMT workshops and Development Forums, noted in the overview of the pre-assessment process above, were critical venues for input and discussion. The number of CEs for this REA was limited to twenty based on available time and resources; eighteen CEs plus the unique mesquite upland scrub system were selected for assessment in the REA.

A summary of the CE selection process is provided below, followed by a summary of the CEs selected; more details on the specifics of this process, and the rationale behind the approach, are contained in **Appendix A** in the section on CE selection.

3.2.1 Identification and Selection Process

Initial Compilation of Candidate Conservation Elements

Ecological System Conservation Elements

Ecological systems as classified by Comer et al. (2003) and mapped by NatureServe (2013) within the Madrean Archipelago ecoregion formed the initial list of possible ecological system CEs under consideration for this REA. The list of potential habitat CEs identified in the Development Forums was reviewed and cross-referenced to the list of ecological system types to ensure that those types were represented in the list of candidate CEs.

Ecological systems that are dominant in, characteristic of, or have their primary range in this ecoregion were recommended as higher priority candidate CEs, while types peripheral to the ecoregion or having the bulk of their range outside the ecoregion were recommended as lower priority candidates. Although small in spatial extent, aquatic, wetland, and riparian ecological systems play a crucial role in this arid ecoregion. Therefore, several ecological systems representing a cross-section of the key aquatic habitats of the ecoregion were included as candidate CEs. Upland ecological systems having very small areal extents within the ecoregion, but having the majority of their total geographic range within this ecoregion, were also recommended as higher priority candidates for the MAR ecoregional assessment.

Species Conservation Elements

The Madrean Archipelago ecoregion is highly diverse and has a significant number of endemic, rare, or threatened/endangered species; consequently, hundreds of species have been identified as being of management or conservation concern. The species identified and prioritized in the Development Forum provided an initial list of 60 species suggested as CEs for this REA. Additional sources including state wildlife action plans, BLM sensitive species lists, and The Nature Conservancy's ecoregional assessment for the Apache Highlands (which overlaps the MAR; Marshall et al. 2004) were reviewed to build a comprehensive list of species CEs of management concern. The contracting team then reviewed the Development Forum lists and the compiled species of management concern and used expert opinion to apply the criteria and considerations listed below to develop a smaller list of candidate species CEs for review by the AMT and Technical Team.

Criteria and Considerations for Narrowing the Lists of Candidate CEs

The criteria and considerations listed here were applied to the compiled lists of ecological system and species CE candidates to inform development of a final set of candidate CEs for the AMT and Technical Team's consideration. Some of these considerations are relevant to both the species and ecological systems; others were relevant to only one or the other.

- Regional significance
  - Relevant to more than one BLM field office or other agency's local management jurisdiction [Both]
  - Dominant in the ecoregion [Ecosystems]

    - Broadly represent a cross-section of the region's diversity [Both]
    - Endemism [Both]
- Nexus with identified management issues [Both]
- Representation by associated ecological system (habitat) CE [Species]

Finalizing the Conservation Element List
Applying these criteria resulted in approximately 20 candidate ecological system CEs and 65 candidate species CEs. Once the contracting team developed a set of final recommendations, based on the various input and sources described above, a series of webinars and conference calls were held with the AMT and Technical Team to review the candidates and arrive at the final list of 18 CEs. The details of the remaining steps in the review and selection process are described in **Appendix A**, in the section on CE selection.

3.2.2 Conservation Elements Selected for the REA

As noted above, the CE selection process resulted in the selection of eighteen CEs for this REA: ten ecological systems and eight species. Of the ten systems, six are upland systems and four are aquatic/wetland systems. Among the eight species, six are individual species – four mammals, one reptile and one amphibian, and two are assemblages of species – grassland birds and nectar-feeding bats. Selected ecological systems are listed in Table 3-1 and shown in Figure 3-1; species are listed in Table 3-2.

The Apacherian-Chihuahuan Mesquite Upland Scrub system, which occupies close to 20% of the ecoregion, was also considered as a system CE. However, questions identified for this type during the development forums and subsequent discussions differed from the ecological status-related questions identified for all of the other CEs; instead, questions centered on issues tied to the restoration of this type to the grassland ecological system into which it has encroached. Therefore, it is a unique element of the REA and is discussed later in this section, under **Mesquite Upland Scrub**, as well as in the Current Issues section on invasive species, under **Native Woody Increasers: Mesquite and Other Shrub Expansion**.

For each of the CEs, a conceptual model was developed; the models contain narrative descriptions characterizing the CE, its natural processes, and response to stressors, tables of ecological attributes and indicators, and model diagrams. The CE conceptual models are contained in **Appendices C** and **D**, provided as a separate document. The conceptual models form the foundation for assessing ecological status of the CEs and addressing related questions in the assessment phase of the REA.

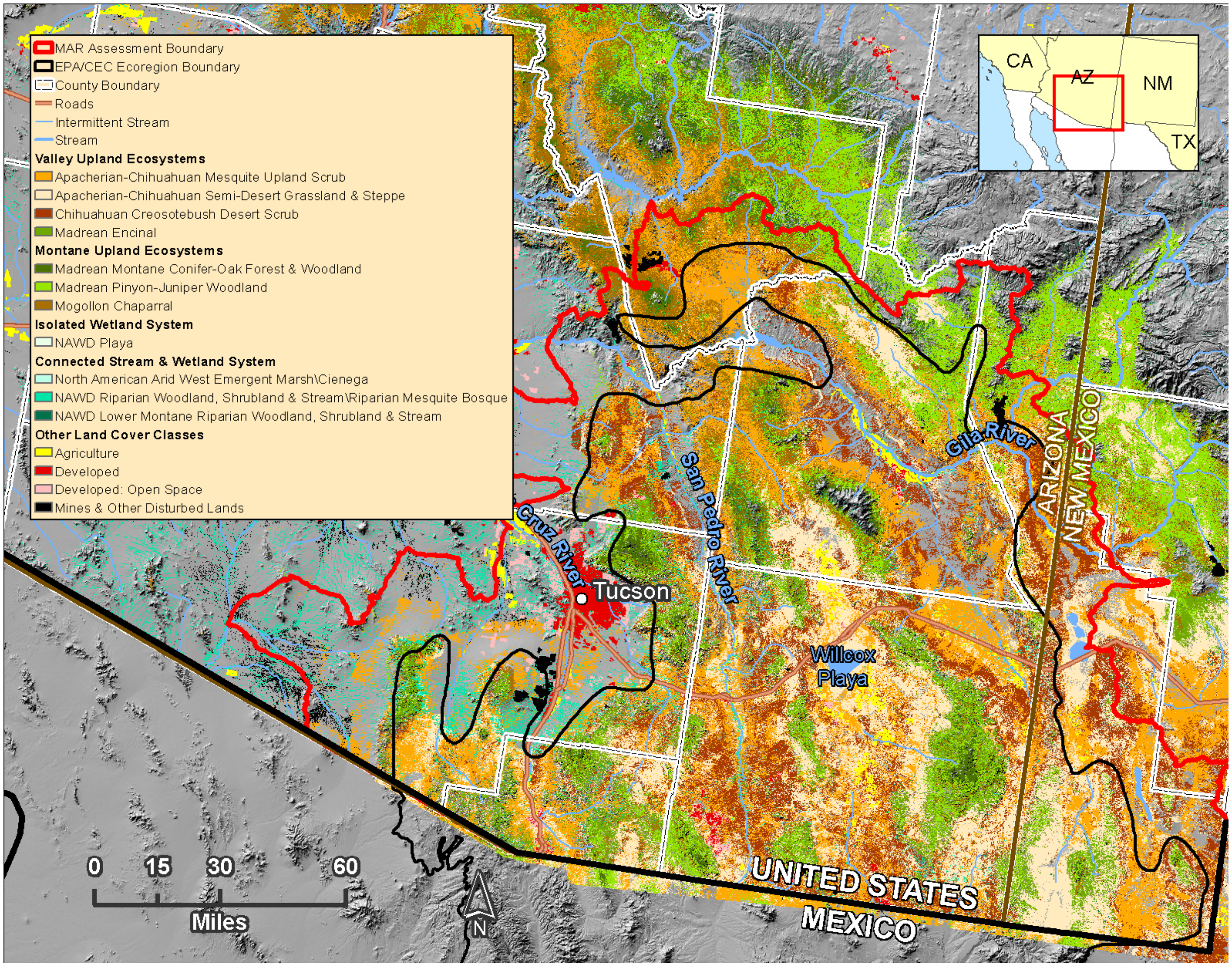
Table 3-1. Ecological system conservation elements (CEs) selected for the Madrean Archipelago REA. The ecological systems are organized in this table according to the four major system divisions or groupings (valley upland system, montane upland system, connected stream and wetland, and isolated wetland) of the ecoregion conceptual model (see subsequent chapter, **Ecoregion Conceptual Model**). Percent of ecoregion occupied by each system is calculated for the U.S. portion only.

Ecological System Name	Approx. % Ecoregion	Notes on Selection
Valley Upland System Division	**56.0%**	
Chihuahuan Creosotebush Desert Scrub	13.2%	Represents an important desert shrubland type
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	18.2%	Characteristic and most of its distribution is within the MAR
Madrean Encinal	5.1%	Characteristic and most of its distribution is within the MAR
Montane Upland System Division	**13.4%**	
Madrean Pinyon-Juniper Woodland	5.8%	Characteristic and most of its distribution is within the MAR
Montane Conifer-Oak Forest and Woodland	2.8%	Characteristic and most of its distribution is within the MAR
Mogollon Chaparral	4.8%	Represents important montane shrublands; characteristic of the MAR
Isolated Wetland System Division	**<1%**	
North American Warm Desert Playa and Ephemeral Lake	<1%	Important ephemeral wetland for many migratory birds; also invertebrate assemblage
Connected Stream and Wetland System Division	**4.3%**	
North American Warm Desert Riparian Woodland and Shrubland, Mesquite Bosque and Stream	3.3%	Major river and riparian areas which are critical habitat for many species
North American Arid West Emergent Marsh/Ciénega and Pond	1.0%	Spring-fed wetlands; ciénegas are somewhat unique to the MAR.
North American Warm Desert Lower Montane Riparian Woodland and Shrubland and Stream	<1%	Major river and riparian areas which are critical habitat for many species

Table 3-2. Species conservation elements (CEs) selected for the Madrean Archipelago REA.

Category	**Species Name**	**Listing Status** (State or Federal)	**Notes on Species Selection**
Mammal	Desert bighorn sheep, all subspecies (*Ovis canadensis*)	None	This species is of high management interest to multiple entities in the MAR ecoregion because it is a game species. It inhabits a wide range of elevations.
Mammal	Pronghorn (*Antilocarpa americana*)	None	Strong interest and direction from the AMT to include this species that is of management interest and highly associated with grassland habitats in the MAR ecoregion.
Mammal	Black-tailed prairie dog (*Cynomys ludovicianus*)	None	This keystone species is of high management interest to multiple entities in the region.
Mammal	Coues deer (*Odocoilus virginianus couesi*)	None	This big game species is of management interest in the MAR ecoregion and adds different elevation range and habitat considerations than those represented by the pronghorn and desert bighorn sheep.
Mammal	Nectar-feeding bats	See conceptual model	Nectar-feeding bats and their associated habitat are of high management interest to multiple entities in the region and there was high interest in this group from the AMT and the development forums.
Bird	Grassland bird assemblage	See conceptual model	Strong interest and direction from the AMT to include grassland birds in order to provide needed landscape-level information at the diversity/assemblage scale.
Reptile	Ornate box turtle (*Terrapene ornata luteola*)	None	In conjunction with the Chiricahua leopard frog, this species helps represent the herpetofaunal diversity; it has a wide distribution and research need associated with it. There was strong interest from the AMT in including this species.
Amphibian	Chiricahua leopard frog (*Lithobates chiricahuensis*)	Federally Endangered, Arizona Threatened	This endangered species is of management concern to entities across the ecoregion and a diversity of management entities have stewardship over its habitat.

Figure 3-1. Map of the geographic extent of ecological systems selected as conservation elements (CEs) for the Madrean Archipelago REA. Note that the two montane Madrean forest-woodland types are being treated as a single CE. In addition, the riparian types include the in-stream habitat component. Finally, the Apacherian-Chihuahuan Mesquite Upland Scrub type (see section **3.2.3** immediately following), also is shown in this map. Mapped extent of ecological systems is from NatureServe's (2013) ecological systems map for the U.S.



3.2.3 Mesquite Upland Scrub

The Apacherian-Chihuahuan Mesquite Upland Scrub ecological system is an upland shrubland dominated by native woody increasers, honey mesquite (*Prosopis glandulosa* var. *torreyana*) or velvet mesquite (*Prosopis velutina*). Prior to the 1880s, when mesquite began expanding into semi-desert grasslands, mesquite-dominated shrublands rarely occurred in uplands. Studies on the Jornada Experimental Range suggest that combinations of drought, overgrazing by livestock, wind and water erosion, seed dispersal by livestock, fire suppression, shifting dunes, and changes in the seasonal distribution of precipitation have caused this recent, dramatic shift in vegetation physiognomy (Bahre and Hutchinson 2001, Buffington and Herbel 1965, Gibbens et al. 1983, Hennessy et al. 1983, Herbel et al. 1972, Humphrey 1974, McLaughlin and Bowers 1982, McPherson 1995, Schlesinger et al. 1990).

During the pre-assessment process, input from REA participants and literature review clearly indicated that the mesquite upland scrub was of management concern. Questions were identified relating to the potential to restore mesquite scrub back to grassland, and what effects climate change, fire regime alterations, and other variables might have on its continued expansion. Management concerns around the mesquite upland scrub are discussed more specifically later in this report, under the **Native Woody Increasers: Mesquite and Other Shrub Expansion** section of the Current Issues chapter.

Because the Apacherian-Chihuahuan Mesquite Upland Scrub system has displaced semi-desert grassland in part as a consequence of anthropogenic influences, and management concerns are centered on restoration of this type to semi-desert grassland (or other systems) and controlling its expansion (rather than maintenance of the type), it is treated as a novel ecological system in this REA, distinct from the other, naturally occurring ecological system CEs. Similar to the conceptual models for the other CEs, a conceptual model characterizing the Apacherian-Chihuahuan Mesquite Upland Scrub system was developed; see **Appendix E**. However, this model focuses on the process of conversion between this type and the ecological system CEs, and the potential for restoration of mesquite scrub sites to desired conditions. As with other CE conceptual models, the mesquite scrub conceptual model forms the foundation for answering key management questions on this community.

3.3 Change Agents: Identification Process

Change agents are those anthropogenically-driven or -influenced land uses, activities, or phenomena that can affect the ecological status, or "health," of CEs. They are drawn from the standard REA CA categories of 1) development, 2) climate change, 3) invasive species, and 4) fire. "Development" is a particularly broad category that includes any direct human use, activity, or infrastructure on the landscape, such as grazing, agricultural crops, border patrol activities, urban development, or industrial development, among many others. "Invasive species" is also an umbrella term that includes 1) invasive non-native species; 2) managed non-native species (e.g., sport fish, game animals), and 3) "native woody increasers;" these specific categories are defined and discussed in the Current Issues chapter in the invasive species section. As with CEs and MQs, specific CAs relevant to this ecoregion were identified through a combination of input from the Development Forums, review of large-scale assessments and other publications, and additional consultation with experts in various meetings and discussions, including the second AMT workshop. The specifics of the CAs are summarized in the relevant subsections of the Current Issues chapter in this report.

All four of the overarching categories of CAs – development, climate change, invasive species, and fire – will be assessed in this REA. The specific features to be assessed will be determined as a result of the synthesis of the MQs into potential assessments, and the subsequent evaluation in Phase 2 of available data and tools to assess these features.

4 Ecoregion Conceptual Model

The purpose of the ecoregion conceptual model is to describe the ecoregion's defining physical characteristics and processes, biodiversity and associated processes, anthropogenic context, and the interactions and relationships among these in order to understand the Madrean Archipelago ecoregion as a whole. The ecoregion conceptual model, in conjunction with the characterization of issues currently facing resource managers in the ecoregion (per the **Current Issues in the Madrean Archipelago Ecoregion** chapter), together provide the context for the selection of conservation elements and change agents.

The ecoregion conceptual model has two components: narrative text describing the ecoregion's features and characteristics, and a series of diagrams that visually illustrate the relationships between these features. This characterization of the ecoregion also includes the identification of key ecological attributes or indicators of the ecological integrity of the ecoregion; these indicators will be used to assess the ecological integrity of the Madrean Archipelago ecoregion as a whole.

The ***temporal bounds*** of this conceptual model include the past two centuries, but center on the 20th century and the recent decades. This time period reflects the climatic regimes, ecological patterns and processes, and change agents that are most applicable to this assessment. Although the REA will evaluate climate-induced stress and land use scenarios for future time periods, the overarching ecoregional conceptual model is based on knowledge and assumptions up to the present.

Although the anthropogenic context is a fundamental component of the conceptual model, as previously noted, the narrative description of that context is contained within the **Human Context** chapter of this report, and expanded on in more detail in the **Current Issues** chapter.

4.1 Biophysical Controls

4.1.1 Physiography and Geology

The sky islands of the Madrean Archipelago are unique in many respects, including physiography and geologic history. The mountains of the sky islands are deformational, resulting from extensional forces of continental rifting that began some 13 million years ago. These are "horst/graben" landforms, wherein the mountains did not rise so much as the valleys sank, thereby creating a landscape of parallel sequences of valleys and mountains. This basin and range topography is somewhat unique to North America, covering vast areas of the southwestern United States and south into Mexico (Wiken et al. 2011). Overlaid on this topography are degradational landforms, such piedmonts left by erosion, and constructional landforms, such as alluvial fans.

The "horst/graben" development exposed older rocks derived from a highly diverse geologic past: multiple marine invasions, caldera explosions and lava flows, and metamorphic core complexes (Warshall 1995). The individual mountain ranges of the Madrean Archipelago ecoregion often have a complex mixture of rock types exposed: intrusive igneous rocks (granite), extrusive volcanics (rhyolite, dacite, basalts), metamorphics (gneiss, schists, quartzite), and sedimentary rocks (limestones, shale, conglomerates). Some (such as the Chiricahuas) are individual volcanoes; others (e.g., Huachucas) are predominantly limestones; and still others (e.g., the Pinalenos, the Santa Catalinas) are metamorphics with cores of gneiss and granite.

Most of the lower elevations and valleys of this area are covered by deep alluvium washed down from the adjacent mountains. These deposits of silt, sand, and gravel are very young in the present-day drainages and much older on the valley floors and terraces (NRCS 2006). The spatially and temporally discontinuous deposition of alluvium has resulted in a mosaic of different aged and applied alluvium. Deeply incised landforms result in extreme topographical relief (canyons), or the terraced alluvium of the larger river valleys (McAuliffe and Burgess 1995).

Coblentz and Riitters (2004) found that the high biodiversity of the Madrean Archipelago can be correlated to two factors of physiography: the topographic relief and the northwest to southeast trends of the major mountain ranges. The local-scale relief results in the compression of biotic communities into relatively narrow vertical space (Brown 1982) and also contributes to rapid species turnover (McLaughlin 1994). In addition, the compressed relief encourages the interaction of species that would normally be widely separated (Felger and Wilson 1995). Secondly, the overall northwest-to-southeast orientation of the mountain ranges through the region encourages the movement of both plant and animal species from the southern, neotropical regions into the more northerly temperate zone. These two factors are considered by the authors (Coblentz and Riitters 2004) to be the most important geographical factors contributing to the high biodiversity of the MAR. When combined with the diversity of parent materials (geologic substrates), the physiography results in high diversity in species, ecosystems, and biotic communities.

In addition, there are other geologically derived, climatically shaped habitats that increase biotic diversity. These include aerosol-derived caliche soils, marine clay-rich valleys in Mexico and the San Rafael Valley, remnant sand dunes in the Animas and other valleys, small seeps in the Galiuros, and the morainal-related ciénegas of the Pinalenos from the last glaciation (Warshall 1986, 1995).

4.1.2 Soils

The variability of soils can contribute to the patterns of vegetation found in an area. Geology plays a role by providing the base parent materials in which soils form and hence the soil mineralogy and chemistry, the structural and textural characteristics, and other properties important to plants. The climate – temperature and precipitation patterns over thousands of years – also influences soil formation. The interactions of climate and parent materials result in a complex mosaic of soils across a landscape, which in turn contribute to the patterns of vegetation at both regional and local scales. Soil characteristics, including depth, moisture, temperature, texture, structure, cation exchange capacity, base saturation, clay mineralogy, organic matter content, and salt content, influence the abundance and composition of plant species as well as animals found in the soils.

The soils of this ecoregion have formed under generally dry and warm conditions, but given the diversity of geologic substrates, are highly variable locally. As defined by the U.S. Department of Agriculture's soils classification system, the predominant soil orders in this ecoregion are Aridisols, Entisols, Alfisols, and Mollisols (NRCS 2006). They tend to be shallow and well drained, but in some areas can be very deep, as in the grasslands, or can have a caliche or hardpan layer that impedes drainage, as in the playas.

Within the Madrean Archipelago ecoregion, the patterns of soil origin, development, and chemistry, are important factors in the diversity of ecosystems found here. For example, Whittaker and Niering (1968) found that in the Santa Catalina Mountains, areas of limestone at lower elevations tended to support a more xeric floristic composition, with strong Chihuahuan desert affinities. In contrast, areas of diorite-derived soils (acidic in chemistry) tended to have grasslands or other desert scrub communities with less Chihuahuan composition. Specifics on the characteristics of the soils that are typically associated with each of the ecological system CEs are included in the CE conceptual models.

4.1.3 Climate

Overall, the climate of this desert ecoregion is hot and dry; in the Arizona portion of the ecoregion, annual average temperature is 61.6° F (16.4° C). The region receives an average of approximately 14.7 inches (373 mm; water equivalent) of precipitation a year. There is some variability within these averages because the sky islands create microhabitats that are cooler and wetter than the ecoregion average. In general, air temperatures and precipitation have strong seasonality: a cool, winter, wet season (Nov-March) driven by long-duration cyclonic storms with moisture from the Pacific Ocean; a dry season spanning the spring and early summer (April-June); and a hot, wet monsoon season from late summer into the fall (July-Oct), with heavy, short duration, convective thunderstorms that derive moisture from the Pacific and the Gulf of Mexico and the occasional tropical storm (Serrat-Capdevila et al. 2007). A majority (60%) of the annual rainfall occurs during the monsoon, which is approximately between July and October but centered on the months of July and August, while a second wet season in winter creates a bimodal distribution of precipitation (Figure 4-1).

Because the climate is hot and dry, annual rates of potential evapotranspiration far exceed precipitation. Although the majority of the precipitation in the ecoregion falls during the summer monsoon as rain, this season also experiences the greatest variability in the magnitude and location of precipitation as well as extremely high temperatures, resulting in very high rates of evapotranspiration during the summer. Evapotranspiration is lower in the winter, when storms deliver rain and snow, producing more uniform precipitation across the ecoregion.

Compared to summer storms, winter storms produce precipitation of greater duration but lower intensity, with rainfall at lower elevations and snowfall at higher elevations. Slow release of water resulting from high-elevation spring snowmelt and low evaporation rates make winter precipitation the major source of groundwater recharge because there is less runoff and greater gain to streams.

The area receives the majority of its precipitation during summer because of its proximity to the core monsoon region in Mexico, as weather stations in the south show compared to stations further north (Figure 4-2). The monsoon is strongest in northwestern Mexico; Arizona and New Mexico usually only receive the northernmost fringes of precipitation.

Figure 4-1. Average monthly temperature and precipitation in the southeastern Arizona Planning Area (see inset), 1930-2002.

Data are from selected Western Regional Climate Center cooperative weather observation stations (ADWR 2010a).

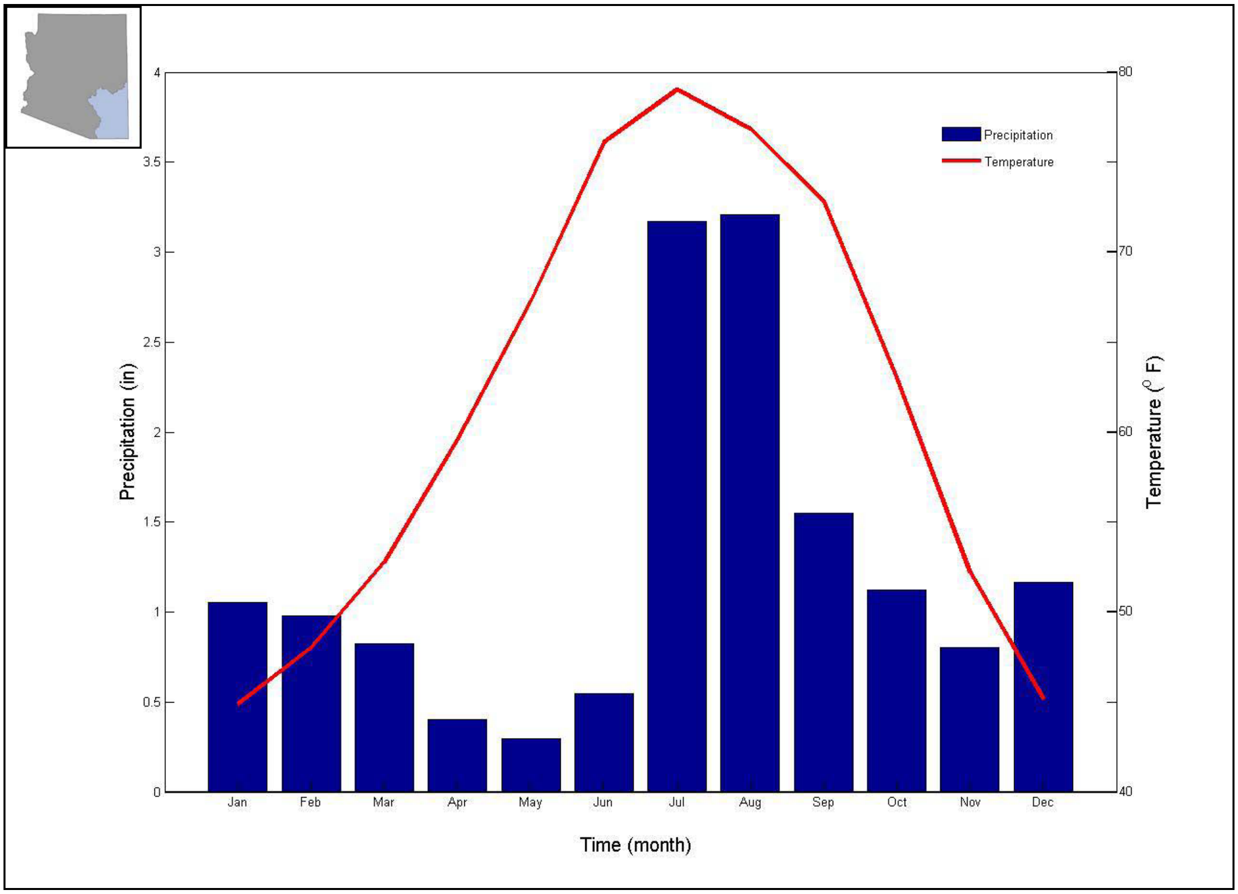
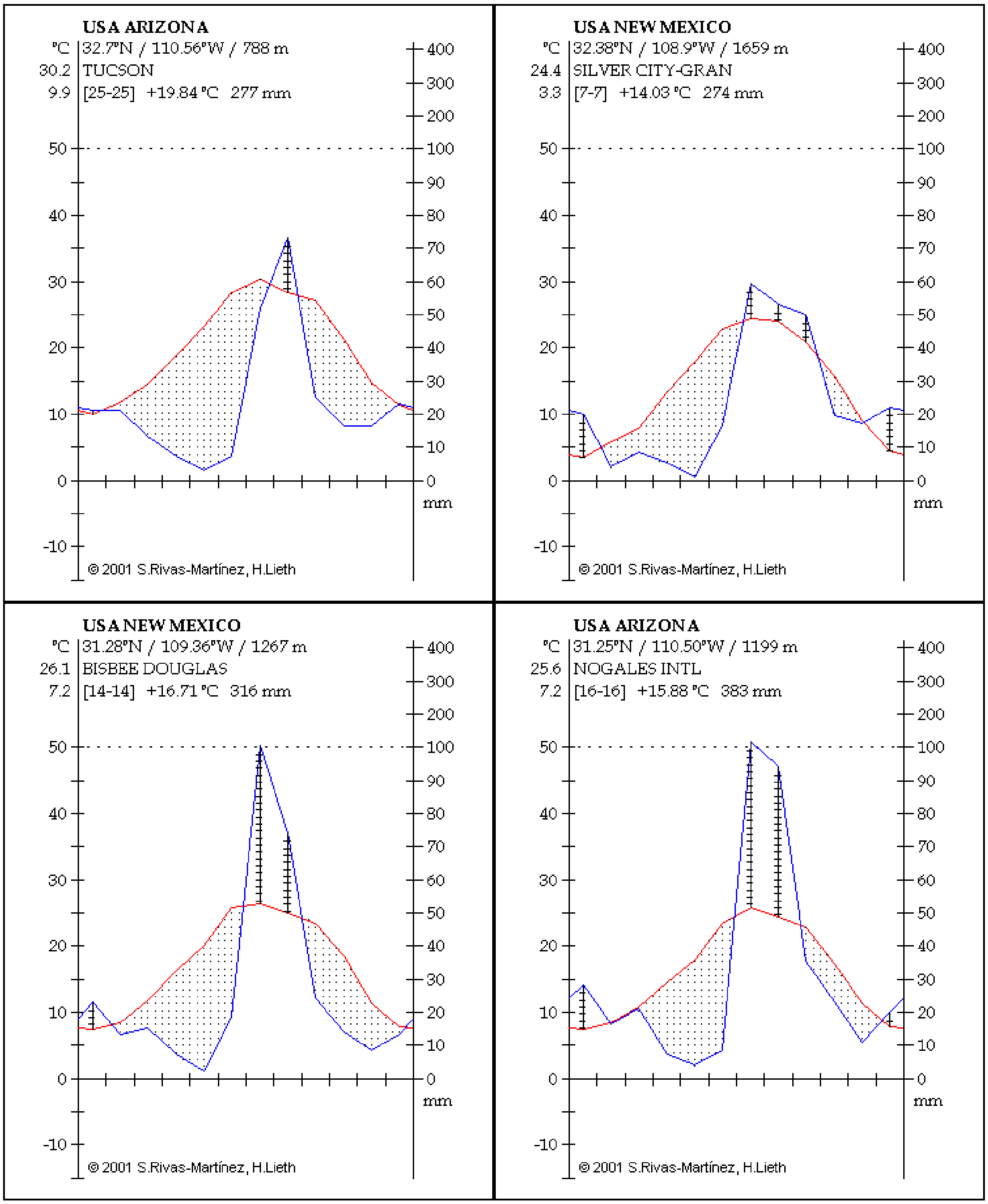


Figure 4-2. Climate diagrams showing average monthly temperature and precipitation from four weather stations in or near the MAR ecoregion. Tucson (upper left), Silver City NM, (upper right), Bisbee/Douglas, AZ (lower left), and Nogales, MX (lower right). Left axis is temperature in Celsius, right axis is precipitation in mm, and horizontal axis ticks are month start and end; red line is temperature, blue line is precipitation time series (diagrams from Rivas-Martinez et al. 2002). These diagrams illustrate the stronger summer monsoon pattern in the southern portion of the ecoregion (Bisbee/Douglas and Nogales, in the bottom two graphics). Silver City is just outside the eastern boundary of the MAR assessment area. See **Figure 2-2** for locations of municipalities where climate stations are located.



Winter precipitation (Nov-April) records dating to 1000 A.D., reconstructed from tree rings, show extended periods of above and below average precipitation in every century in the area encompassed in

Climate Division 7 (southern AZ) (Figure 4-3 and Figure 4-4). Historical records for Climate Division 8 in New Mexico (Figure 4-3) also show extended periods of above- and below-average precipitation in the last century and a quarter (Figure 4-5). These decadal and shorter time period shifts are related to circulation changes in the Pacific Ocean. On time scales of 10-30 years, precipitation variability is likely related to shifts in Pacific Ocean circulation patterns, such as the El Niño-Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO).

On time scales of 2-7 years, the ENSO, with its phases of El Niño and La Niña, is associated with precipitation variations in the region, most notably during winter months (November-April). During El Niño episodes, there are greater chances for above-average winter precipitation; however, El Niño winters can also produce below-average precipitation. La Niña conditions are generally associated with drought in the region, and particularly with below-average winter precipitation. The ENSO phases also impact precipitation and monsoon strength in the region. For example, long-term records show that the 1950s were a relatively dry decade with an average winter precipitation deficit of -1.46 inches (37 mm), while the 1980s were a relatively wet decade with an average winter precipitation surplus of 1.86 inches (47 mm) (Figure 4-5). Pool and Coes (1999) noted that trends in seasonal precipitation at four stations in the southern half of the Upper San Pedro Basin showed a general trend of increasing winter precipitation and decreasing wet-season (summer) precipitation during the period 1956-1997.

Figure 4-3. Maps showing locations of U.S. Climate Divisions that overlap with the MAR assessment area: #7 in Arizona (left) and #8 in New Mexico (right). Maps from the following source: http://www.esrl.noaa.gov/psd/data/usclimdivs/data/map.html.

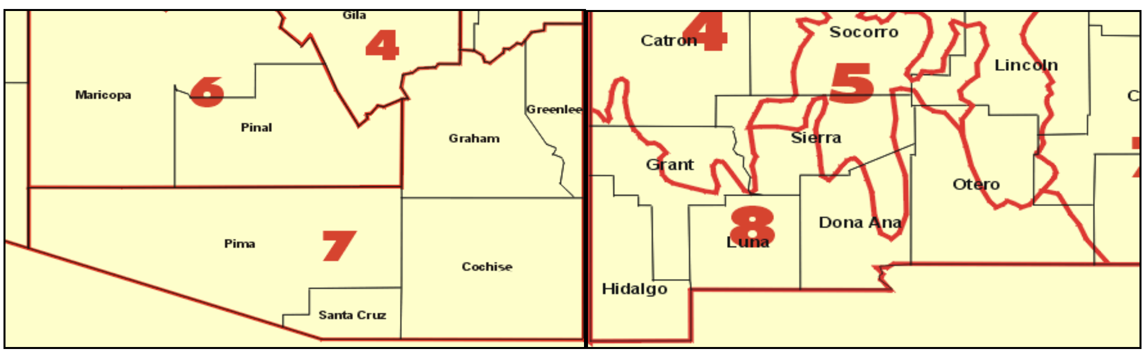


Figure 4-4. Winter (Nov-April) precipitation (20-year moving averages) for southern Arizona dating from 1000 A.D. to 1988, reconstructed from tree rings show extended periods of above (blue)and below (red) average precipitation in every century in the area encompassed in Climate Division 7 (southern AZ). Data are presented as a 20-year moving average to show variability on decadal time scales. Values shown for each year are centered on a 20-year period. The average winter precipitation for 1000-1988 is 4.9 inches (124 mm). Data: Fenbiao Ni, University of Arizona Laboratory of Tree-Ring Research and CLIMAS. Figure author: CLIMAS (figure and caption from ADWR 2010a).

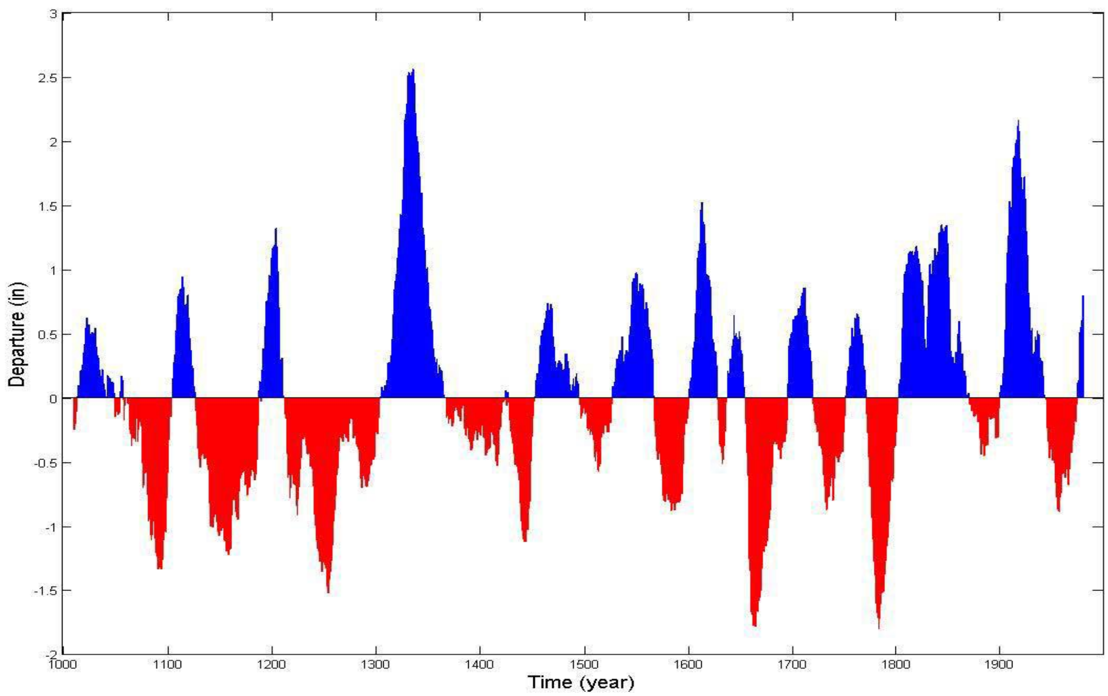
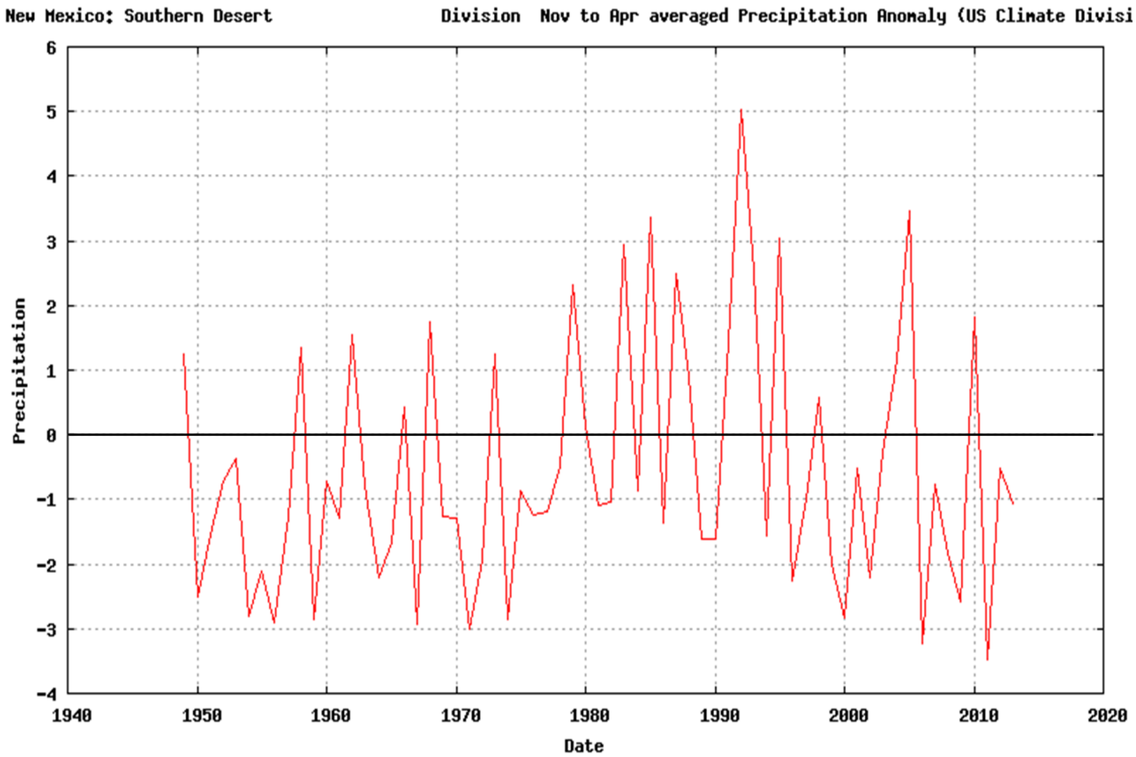


Figure 4-5. Winter (Nov-April) precipitation records relative to normal for 1895-2013, southwestern New Mexico show extended periods of above and below average precipitation in every decade in the area encompassed in U.S. Climate Division #8, southwestern NM. Data from the Earth System Research Laboratory http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries.pl.



4.1.4 Biogeography

The Madrean Archipelago straddles the international border and has ecological significance as both a barrier and bridge between two major cordilleras of North America: the Rocky Mountains and the Sierra Madre Occidental. It is the only sky island complex in the world that extends from subtropical to temperate latitudes (approximately 25 to 33 degrees north latitude), and as such, represents a continental-scale ecotone between the tropical and temperate regions of North America (Mau-Crimmins et al. 2005, Warshall 1995). It forms the southernmost edge of many temperate species' ranges and the northernmost edge of many tropical species' ranges. The hot and generally dry desert climate combined with the rich diversity of latitudinal and elevational extremes, topography, geologic substrates, and soils, has resulted in a remarkable suite of biodiversity (Brown 1982, Dinerstein et al. 2000, Mau-Crimmins et al. 2005). In addition, because the woodlands and forests cloaking the mountain ranges are isolated from each other by significantly different ecosystems, genetic interchange is limited and speciation is common; this has resulted in high numbers of endemic species (Bailowitz and Brock 1991, DeBano et al. 1995, Marshall et al. 2004, Mau-Crimmins et al. 2005).

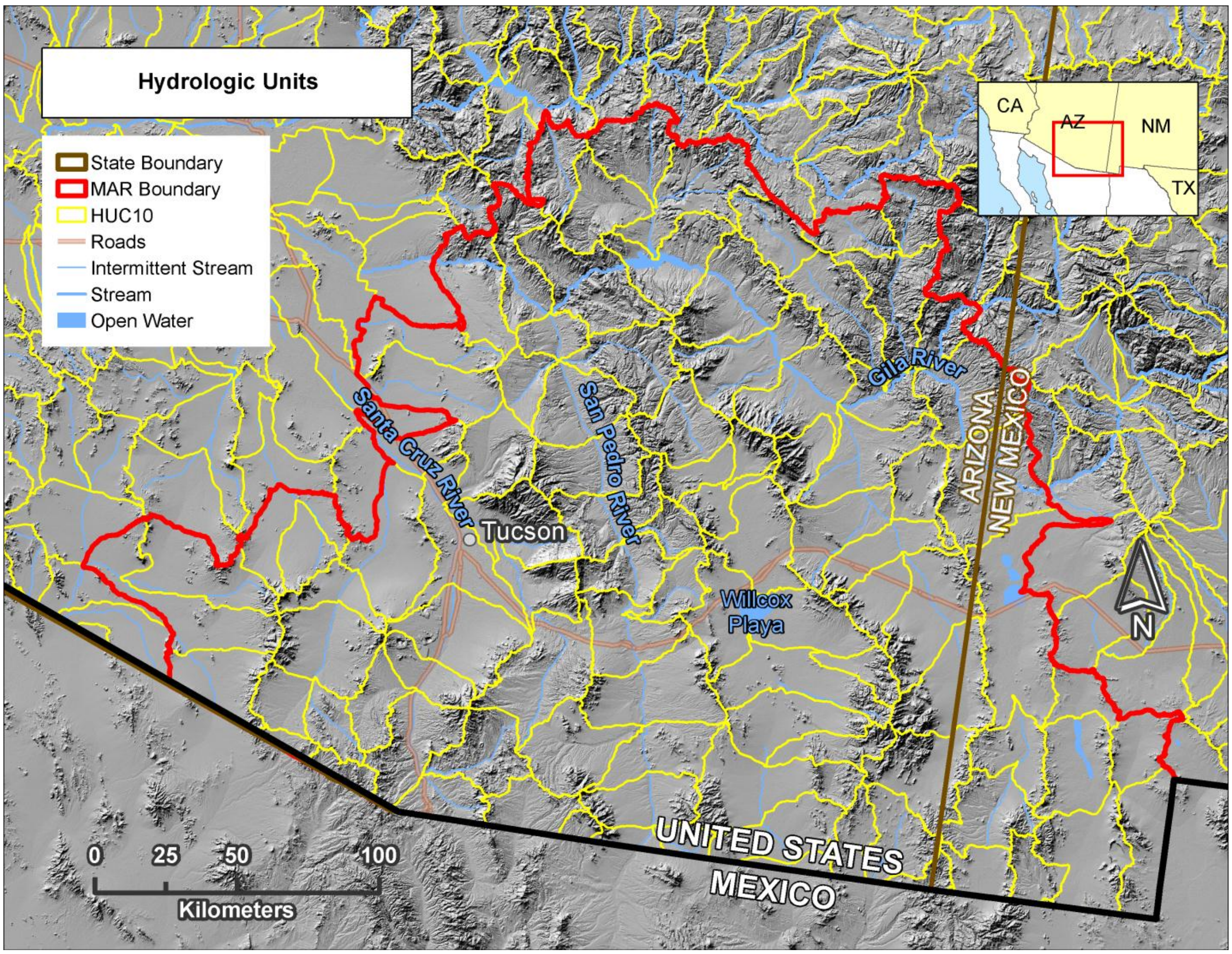
4.2 Ecosystem Processes

A range of physical and biological processes shape the biodiversity of this ecoregion. This section focuses on describing the natural processes influencing ecosystems and species. Discussion of the anthropogenic effects on these natural processes and resulting impacts on natural sources is provided in the subsequent chapter, **Current Issues in the Madrean Archipelago Ecoregion**.

4.2.1 Hydrology

Major watersheds in the Madrean Archipelago include the Middle Gila, Upper Gila, Sonora, and the Rio Grande-Mimbres (defined by four-digit hydrologic units). Major rivers in the ecoregion are the westward-flowing Gila and its southern tributaries, the San Pedro River and Santa Cruz Rivers (Figure 4-6). Other tributaries include the San Francisco and San Simon Rivers; and Aravaipa Creek and Babocomari River, tributaries to the San Pedro River (NRCS 2006). The mainstem San Pedro River originates just across the border in Sonora, Mexico and is formed by the confluence of the Rio Nutrias with other tributaries. The mainstem Santa Cruz River originates in Arizona, but then flows south into Mexico before turning westward around the Sierra San Antonia and then northward to reenter the U.S. A small portion of the ecoregion in extreme southeastern Arizona drains southward into Mexico along Whitewater and Black Draws, tributaries to the Rio De Bavispe, which is in turn a major tributary to the Rio Yaqui. The ecoregion also includes several small terminal (closed) basins: the Willcox basin in AZ, and the Animas Playas and Lordsburg basins in NM.

Figure 4-6. Map of major rivers and 5th-level watersheds in the Madrean Archipelago assessment area (shown in red outline).



Hydrologic regimes are inextricably linked to climate patterns (precipitation and temperature) and the landforms and soils of a region. As briefly noted in the climate summary, although the amount of winter precipitation is lower, the storms are widespread, covering more area with more uniform and gentler rain; in conjunction with lower evapotranspiration rates, winter precipitation contributes more groundwater recharge compared to summer monsoon rains. In addition, more moisture soaks into soils, channels, and bedrock fractures in the mountains and along the mountain fronts (valley margins) during the winter storms, making the mountains and mountain fronts the largest geographic area of groundwater recharge for the ecoregion. Winter precipitation comprises less than half the total annual precipitation on average, but supplies the majority of the annual groundwater recharge (Pool and Coes 1999, Serrat-Capdevila et al. 2007).

Hydrology and Aquatic Ecosystems

The hydrologic patterns of a region reflect the relative contributions of surface runoff and groundwater discharge. In the Madrean Archipelago, the stream network exhibits both interrupted perennial and intermittent reaches. Groundwater generally flows from the margins to the central axis of each basin, supporting greater groundwater discharge on average along the central axes than along the valley margins (MacNish et al. 2009). The types of storms associated with different seasons and weather patterns produce different runoff flow magnitudes and durations. Naturally dry washes sustain surface flow during and immediately following precipitation events from both rainfall and snowmelt runoff. Base flow is sustained in stream and river reaches connected with the water table year-round or seasonally (Hirschboeck 2009). The hydrologic regimes of the region’s aquatic ecosystems reflect the combined effects of shallow or deep groundwater discharge and watershed runoff (MacNish et al. 2009). While the basic mechanics of water flow remain largely unchanged, perennial stream reaches were longer and more numerous (Logan 2006, Thomas et al. 2006) and groundwater levels were significantly higher overall, prior to significant human influences on the region’s hydrology. (Anthropogenic alterations to hydrology and associated impacts are discussed later in the Current Issues chapter in the section **Water Availability and Altered Hydrology**.)

Springs and seeps are present throughout the ecoregion; they depend on groundwater flow and tend to have very stable patterns of discharge (Hendrickson and Minckley 1984). Their discharges may also have unique chemistries due to their origination in different aquifers with long flow paths. Confined groundwater (artesian conditions) can occur within the lower basin fill (ADWR 2010a). Artesian conditions occur in a number of locations, and are a result of localized clay and silt lenses within the basin fill of sand and gravel (MacNish et al. 2009). The ecoregion also contains several small closed basins. Runoff and recharge around the margins of these basins during periods of higher rainfall produce shallow ephemeral (playa) lakes (e.g., Willcox Playa), the chemistry of which can be controlled by near-surface evaporate deposits (Schreiber 1978).

Aquatic ecosystems in the ecoregion that rely entirely on surface water include ephemeral (losing reaches) of stream channels, dry washes, and playas. The biota of these ecosystems evolved to withstand highly dynamic seasonal and decadal changes in the amount and duration of surface flows, from multiple years of no water to extreme flood events. Aquatic ecosystems that rely on perennial sources of water occur along streams with groundwater-fed base flows, but also evolved under and are adapted to very dynamic changes in seasonal flow. For more information on aquatic ecosystems of the region, see the **Ecosystems** summary later in the ecoregional conceptual model chapter, as well as the individual conceptual models for the aquatic ecological system CEs (compiled in **Appendix C**) selected for this REA.

4.2.2 Fire

Natural disturbances are important drivers of change and are defined as any relatively discrete events in space and time that disrupt ecosystem, community, or population structure and change resources, substrate, or the physical environment (White and Pickett 1985). The key components of this definition are that disturbances are discrete in time, in contrast to chronic stress or background environmental variability, and that they cause a notable change, a perturbation, in the state of the system. Within the Madrean Archipelago ecoregion, fire is among the major disturbance agents shaping the ecosystems of the region, whether as a single, discrete event or multiple events comprising a native fire regime.

Fire has shaped, and continues to influence, the ecosystems of this ecoregion. Indeed, fire was likely the most important agent structuring the terrestrial systems within the ecoregion for millennia. With the exception of the desert scrub (creosotebush or the Sonoran Palo Verde-Mixed Cacti Scrub), all of the terrestrial ecosystems of this ecoregion burned frequently – from the grasslands and shrublands in the valley bottoms, to the fringing woodlands, to the coniferous forests high in the mountains.

Early historical records contain many accounts of fires burning millions of acres in the southwest in particular years (McPherson and Weltzin 2000). The vast majority of these fires were likely caused by lightning strikes; this region has among the highest incidence of lightning strikes, and the highest rates of lightning-ignited fires in the U.S. Fire-scar studies have shown that the woodlands and low-elevation forests had a fire-return interval of less than 10 years. The Madrean Archipelago's grasslands likely burned as frequently, if not more so (Bahre 1985, McPherson and Weltzin 2000). The higher, wetter, coniferous forests had comparatively longer, but still remarkably short fire-return intervals of approximately 35 years (Swetnam 1988).

These frequent fires historically burned with low intensity and typically stayed on the ground. Stand-replacing fires were likely extremely rare, as the frequent ground fires kept fuel loads to a minimum and prevented the accumulation of ladder fuels necessary for fire to reach the canopy. Most areas were likely fuel-limited, and fires would occur during periodic droughts following a sequence of wet, productive years. These climate-driven patterns would cause large areas to become susceptible to fire simultaneously, resulting in low-intensity fires spreading across very large areas. Alterations of the fire regimes associated with different ecosystems in the ecoregion and the effects of these alterations are discussed in the **Fire** section of the Current Issues chapter.

4.2.3 Other Ecosystem Processes

Other ecosystem processes that are not driving the broad patterns of vegetation and biological diversity across the landscape but creating localized patterns of diversity or providing certain functions are also operating in this ecoregion. Nutrient cycling, insect outbreaks, pollination, and herbivory are noteworthy processes, either because of their importance or how they are changing.

Nutrient cycling is especially important in semi-desert regions, where soils are often infertile due to a lack of organic matter, and also often highly alkaline or saline. Invertebrates are important for nutrient cycling, and subterranean species of ants and termites can impact soil properties such as bulk density, infiltration permeability and storage (Whitford et al. 1995). Mau-Crimmins et al. (2005) provide a summation of the importance of nutrient cycling in dryland ecosystems:

> "Nutrient cycling involves the input of nutrients (from weathering of rocks, fixation of atmospheric nitrogen, and atmospheric deposition from rain, wind and gases), the loss of nutrients through various ecological processes (such as leaching, emissions, wind erosion, and fire), and the transfer of nutrients between the soils and vegetation within the ecosystem. In arid ecosystems, the spatial pattern of nutrients is highly variable as patches of nutrient-rich soils are often surrounded by a matrix of nutrient-poor soils. These "islands of fertility" are formed as existing vegetation creates a patch of nutrient-rich soil as litter is deposited in the immediate area surrounding the plant. This will often allow for the recruitment of other individuals, which perpetuates the process (Aguiar and Sala 1999). The rate at which nutrients are absorbed and utilized is highly dependent upon the species and the nutrient supply. As a

result, changes in biotic or abiotic conditions may lead to changes in the nutrient cycling regime of an ecosystem (Chapin et al. 2002)."

As herbivores and disease vectors, insects have significant effects on woodland and forest communities in this ecoregion. Many insects and associated disease pathogens are native to the ecoregion and have natural cycles of outbreaks. However, with changes to fire regimes, increased stress to native organisms due to human activities, changes in air or water quality, and climate change, there is increased potential for more massive and destructive insect or disease outbreaks. For example, the spruce-fir forest on top of the Pinaleño Mountains in the Coronado National Forest is experiencing a massive die-off of mature trees, primarily due to the combined effects of drought, high density of trees and competition, and insect outbreaks (Schussman and Smith 2006). The current insect outbreak involves a variety of species, including the non-native spruce aphid (Lynch 2009). Since 1998, over 90 percent (around 1,800 acres (730 ha)) of the spruce-fir vegetation type on the Coronado National Forest has suffered mature tree mortality due to insect attack and wildfire (Coronado National Forest 2009).

The nectar-feeding bats of the ecoregion play a role in pollination, especially for the agaves (*Agave* spp.) on which they feed. Lesser long-nosed bats (*Leptonycteris yerbabuenae*) pollinate various agave species, columnar cacti, and other Mexican plant species. Mexican long-tongued bat (*Choeronycteris mexicana*) feed on nectar, pollen, probably insects, and occasionally fruit of columnar cacti (Alvarez and Gonzalez-Q. 1970, Villa-R. 1967). Near Tucson, Arizona, long-tongued bats feed predominantly on cactus and *Agave* species (*Agave schottii* before mid-June, then *A. palmeri*) (Arizona Game and Fish Department 2006, Van de Water and Peachey 1997). Both of these bat species follow a "nectar corridor" of blossoming plants north from Mexico into the United States each spring (Fleming 2012), although the phenology for each of them is slightly different (Arizona Game and Fish Department 2011). Many species of butterflies, flies, bees, and moths are important for pollination. Some species such as yucca moths (*Tegeticula yuccasella*) and *Yucca* species have obligate mutualistic pollination relationships (Whitford et al. 1995).

Herbivory in MAR grasslands by native mammals was historically dominated by pronghorn (*Antilocarpa americana*), prairie dogs, and other small mammals. Black-tail prairie dogs (*Cynomys ludovicianus*) once had extensive colonies but were greatly reduced or extirpated from semi-desert grasslands in New Mexico and Arizona by the 1960s and their numbers and impacts are still small (Parmenter and Van Devender 1995). Prairie dogs have been shown in some studies to influence the presence of woody species such as mesquite (*Prosopis* spp.) (e.g., Weltzin et al. 1997; see also discussion in Milchunas 2006). Today, pronghorn and other small mammals are the dominant vertebrate herbivores. Herbivory from native small mammals, such as rodents, is significant as they are the most common mammals in the semi-desert grassland ecosystem. There is also high diversity of these rodents in the MAR, especially ground-dwelling species, and these burrowing rodents have a substantial effect on vegetation composition, soil structure and nutrient cycling (Finch 2004, Parmenter and Van Devender 1995). Grasshoppers feed on grasses and forbs and can consume significant amounts of forage when their populations are high. However, the intensity and scope of herbivory by native mammals and insects is such that it is not a major driver shaping the mosaic of grasslands and shrublands of the ecoregion. Natural herbivory is noteworthy in relation to livestock grazing; through livestock grazing, large-scale herbivory has been added as a significant ecological process in a region whose biota had not evolved under comparable herbivory processes. Effects of livestock grazing are discussed in the **Grazing** section in the Current Issues chapter.

4.3 *Ecoregion Conceptual Model Diagrams*

The conceptual diagrams presented in this section were developed to visually illustrate the physical and process drivers, described above, that shape the biodiversity of the ecoregion. These pervasive influences of climatic regimes interacting with the basin and range physiography provide the overarching biophysical controls on MAR ecosystem patterns and processes. Seasonal temperature regimes vary along longitudinal, latitudinal, and elevational gradients, as do seasonal precipitation regimes interacting with rain-shadow effects. Combined, these regimes determine regional patterns in weather, such as monsoons, and movement of water. These in turn shape the distribution of ecological systems across the landscape, as well as the processes and stressors interacting with them. Conceptual diagrams were developed for two levels of organization: the ecoregion as a whole and the primary system "divisions" (broad categories or groupings of systems or habitats) of the ecoregion. The ecological system conservation elements are nested within each of the system divisions.

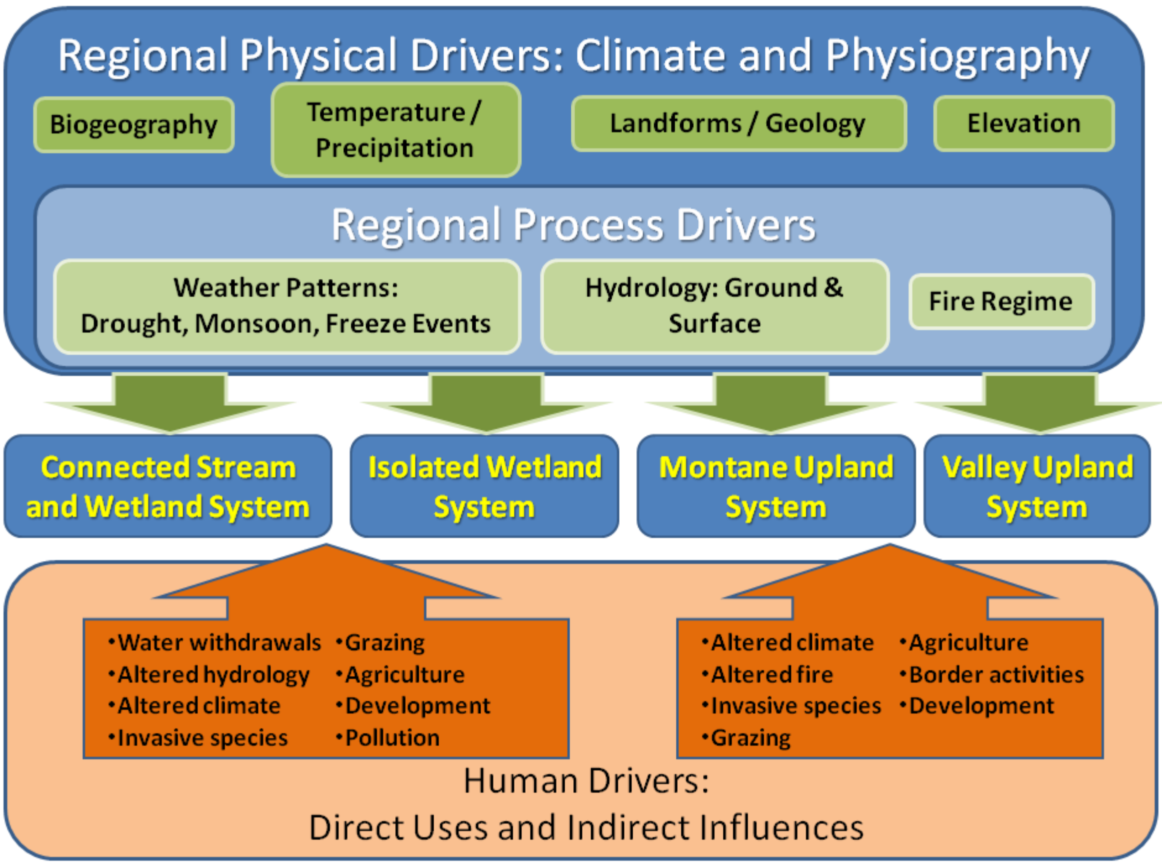
Water plays a critical role in this semi-desert ecoregion, and as an initial division, the overall ecoregion model (Figure 4-7) distinguishes uplands, generally driven by water scarcity, from wetlands (aquatic, riparian, and wetland ecosystems) driven by water flow regimes. Within the uplands, elevation is the second defining variable, with montane ecosystems (generally dominated by conifers) distinguished from those found in the foothills and valleys (generally the grasslands, desert scrub, and oak woodlands). Terms such as "basins" or "lowland" often indicate wetlands of various kinds; therefore, the term "valley uplands" is used to denote the low-elevation uplands and distinguish them from the upland ecosystems found in the montane elevations. Within wetlands, isolated, closed-basin wetlands (playas) were separated from the connected stream network and associated wetlands.

Biogeography is one of the major sub-continental drivers of the biotic composition of many of the ecosystems of the MAR. The upland ecosystems include natural drivers of weather patterns, topography and geology, soil characteristics, and natural disturbance dynamics such as fire and insect outbreaks. These vary considerably between higher, cooler montane settings and warmer, low-elevation valley or basin settings. Within the wetland systems (i.e., streams, larger rivers, playa lakes, wetlands, and riparian environments), the driving factors are seasonal water flow regimes and the relative influence and connectivity of surface and groundwater dynamics. Montane rivers and streams are most strongly driven by surface water flow regimes, while those within the valley basins combine surface flow dynamics with groundwater flows and evaporation; these systems are hydrologically connected to varying degrees. The playas are primarily driven by surface water flow and found in closed basins. All of these natural abiotic drivers constrain and influence biotic responses in both plants and animals, such as predator/prey dynamics, herbivory, pollination, migration patterns, and insect and disease outbreaks.

In addition to abiotic drivers, the human dimension is also represented as a distinct model component. Socioeconomic and demographic factors act as drivers or controls of change in land and water use, policy, and activities (Figure 4-7). While human uses and activities within and beyond the ecoregion produce many positive values (e.g., economic development, outdoor recreation, and solitude), these uses directly or indirectly alter natural system drivers. For example, fire, herbivory, and biotic soil crust processes are altered through uses or management such as livestock grazing and fire suppression in the upland systems. Within wetland systems, the human dimension appears through water withdrawals or diversions, water pollution (e.g., human waste, toxic metals from mining, deposition of atmospheric pollutants), wetland conversion, livestock trampling, or introduction of invasive species. Land conversion and introduction of invasive plant species closely follow human land use patterns for settlements, border infrastructure, energy development and mineral extraction, irrigated agriculture, or transportation/communication infrastructure. Air quality is impacted by a variety of pollutants, and deposition of these has detrimental effects on upland and aquatic ecosystems and species.

Predator/prey dynamics may be influenced by human/wildlife conflicts, disruption of migration or movement patterns, hunting, habitat alteration by livestock congregation, and resource collecting (e.g., plants).

Figure 4-7. Conceptual diagram for the Madrean Archipelago ecoregion, showing the most important physical and process drivers for the region as a whole, as well as important human influences and direct uses. The major patterns of ecosystems are shown as four broad system divisions, which are shaped or influenced by both the natural and human drivers.

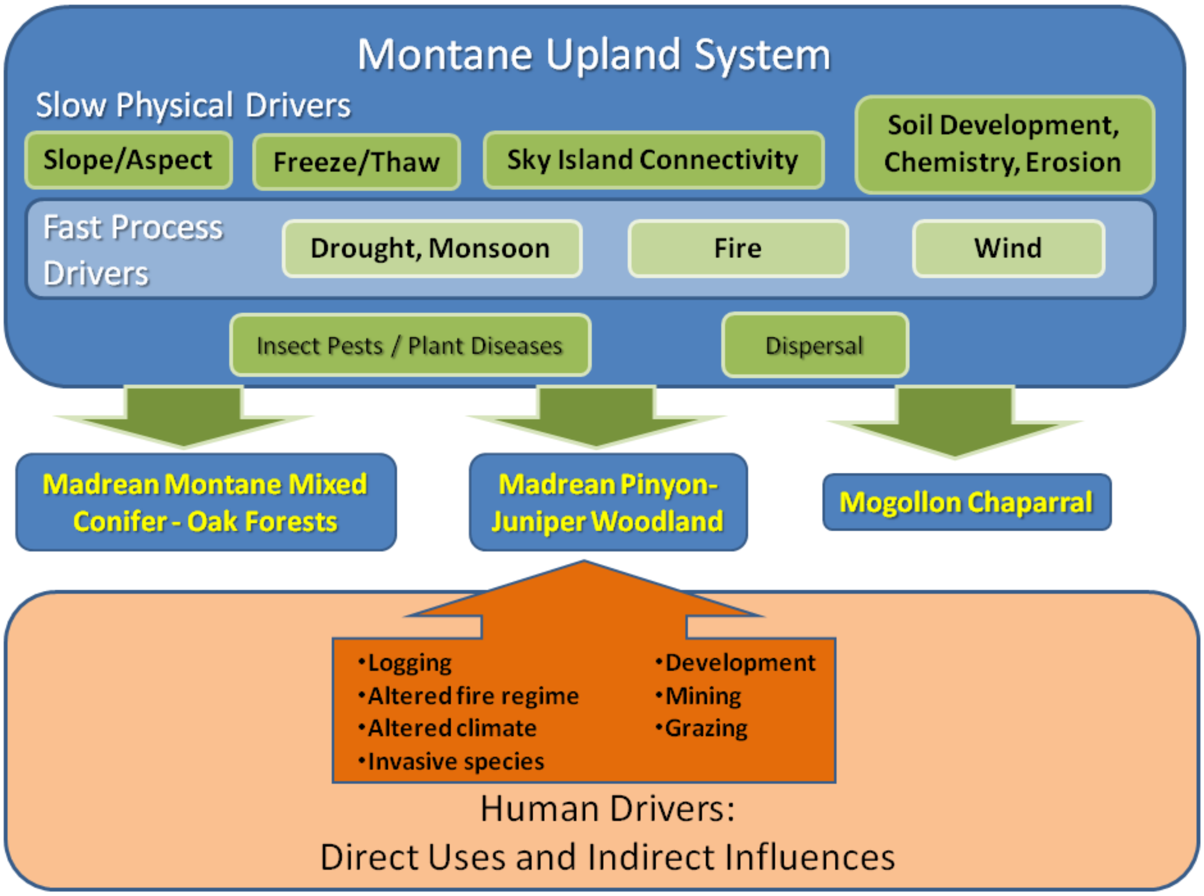


System Division Models

For each of the four broad divisions or groupings of systems (montane uplands, valley uplands, connected wetlands, and isolated wetlands) of the ecoregional conceptual model, associated diagrams introduce additional detail. Natural drivers of patterns are organized in terms of “slow” physical drivers, such as landform and soil development, representing properties and processes that change on decadal and longer timeframes. Drivers of more rapid processes, or “fast” physical drivers, include those such as fire and flooding regimes, soil erosion, and other dynamics that occur over relatively short time frames. Biotic drivers, including the responses and interactions of plants and animals within stated physical bounds and regimes, are also differentiated here. For each of these, the most important drivers of patterns in the MAR landscape are presented; many other drivers of patterns and biotic composition occur on increasingly local scales.

The Montane Upland System Division includes three selected conservation elements that encompass landscape pattern, dynamics, and biotic assemblages for montane mixed conifer forests, pinyon-juniper woodlands, and montane chaparral shrublands (Figure 4-8). These are proportionally more limited in extent than Valley Uplands and are primarily found on National Forest lands of the ecoregion.

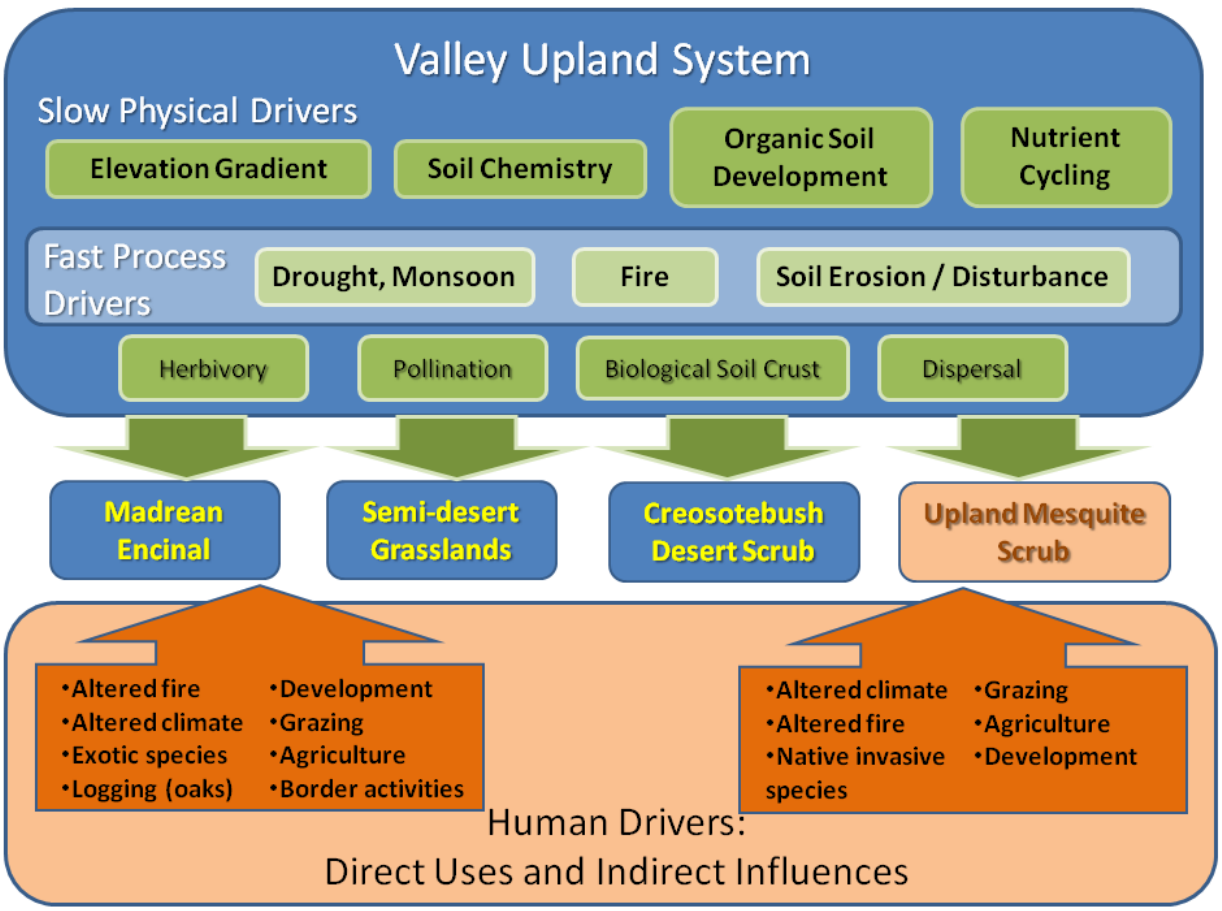
Figure 4-8. Conceptual diagram for the montane uplands system division of the Madrean Archipelago. The diagram highlights the most important physical and process drivers for the montane uplands as a whole, as well as important human influences and direct uses. The major patterns of ecosystems are shown as the three ecological system conservation elements, which are shaped or influenced by both the natural and human drivers.



Encompassing the vast majority of the ecoregion, the Valley Upland System Division represents the landscape pattern, dynamics, and biotic assemblages for encinal oak woodlands, semi-desert grasslands, creosotebush desert scrub, and the mesquite upland scrub (Figure 4-9). The ecological systems of the Valley Upland are primarily found on BLM, state, and private lands.

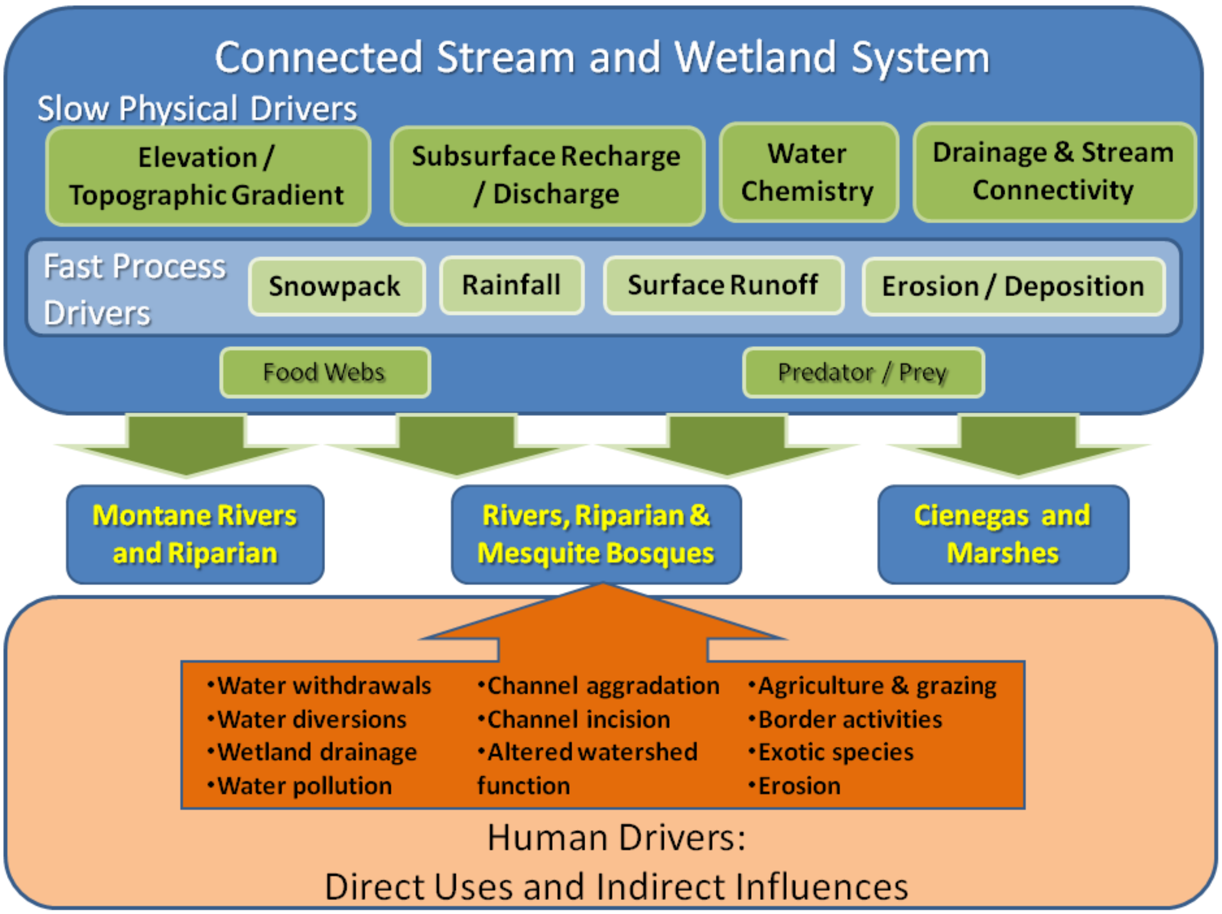
The mesquite upland scrub ecological system is shaped in part by the human activities and influences in the landscape, such as changes in climate and fire regime, historical grazing practices, and development. Although it is not treated as a typical conservation element in this REA, it is an important biotic component of the MAR landscape.

Figure 4-9. Conceptual diagram for the valley uplands system division of the Madrean Archipelago. The diagram highlights the most important physical and process drivers for the valley uplands as a whole, as well as important human influences and direct uses. The major patterns of ecosystems are shown as the three ecological system conservation elements, and one ecological system representing the native increaser, mesquite, all of which are shaped or influenced by both the natural and human drivers.



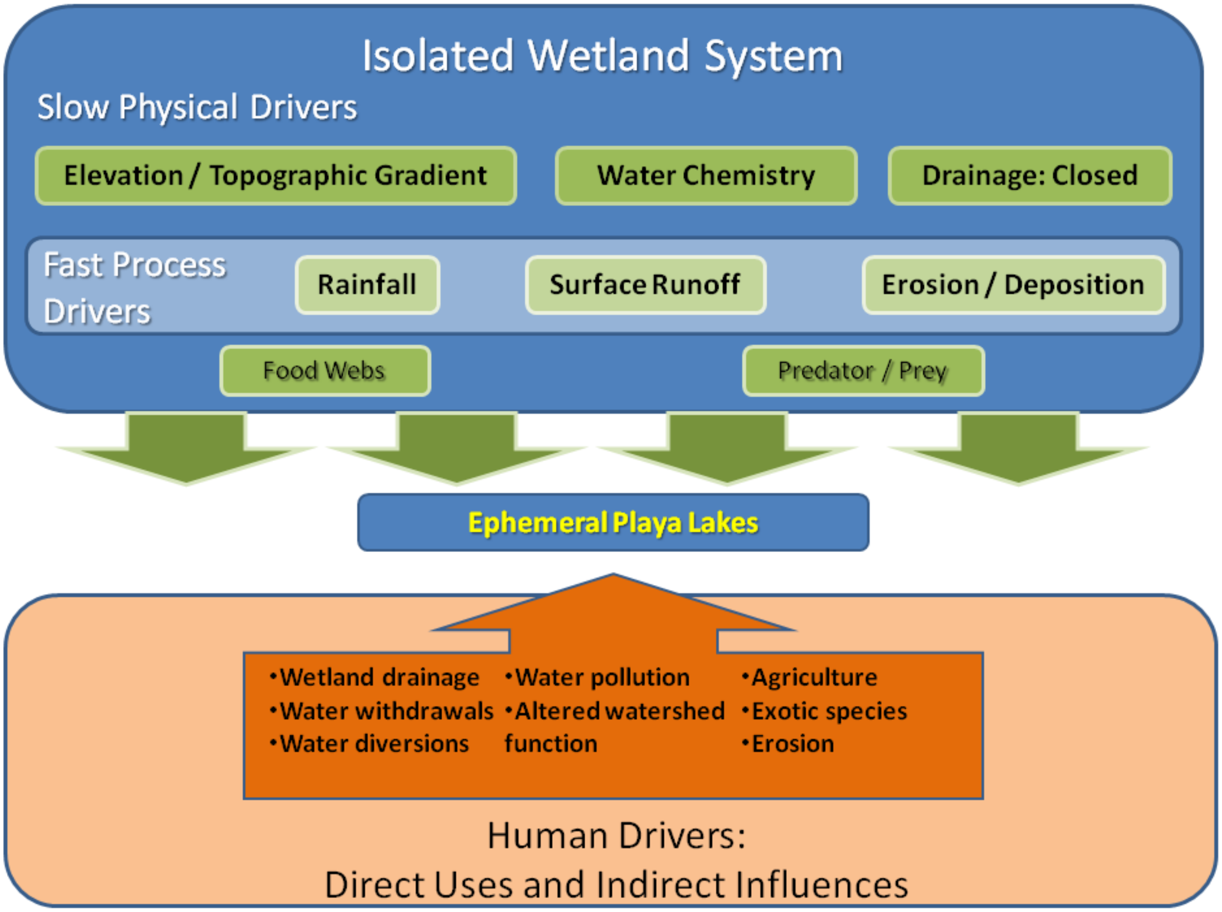
The Connected Stream and Wetland System Division includes three ecological system conservation elements that represent landscape pattern, dynamics, and biotic assemblages for the relatively limited montane and low-elevation rivers, streams, riparian communities, and ciénegas and marshes (Figure 4-10). Inherently limited in spatial extent, these systems are found on a range of both public and private lands across the ecoregion.

Figure 4-10. Conceptual diagram for the connected stream and wetland system division of the Madrean Archipelago. The diagram shows the most important physical and process drivers for the connected aquatic, wetland and riparian ecosystems as a whole, as well as important human influences and direct uses. The major patterns of ecosystems are shown as the three ecological system conservation elements, which are shaped or influenced by both the natural and human drivers.



The Isolated Wetland System Division includes one ecological system conservation element representing the landscape pattern, dynamics, and biotic assemblages for the playa lakes (Figure 4-10Figure 4-10).

Figure 4-11. Conceptual diagram for the isolated wetland system division of the Madrean Archipelago. The diagram shows the most important physical and process drivers for the isolated wetland ecosystems as a whole, as well as important human influences and direct uses. The major pattern of ecosystems is shown as the single ecological system conservation element, which is shaped or influenced by both the natural and human drivers.



4.4 Biodiversity

As described and illustrated in the text and conceptual diagrams above, broad-scale geologic features and landsforms, climate, biogeography, and ecological processes such as hydrology and fire provide the framework that determines the spatial patterns and composition of species and biological community diversity within the ecoregion. These factors are reflected in the biological diversity seen in the ecoregion.

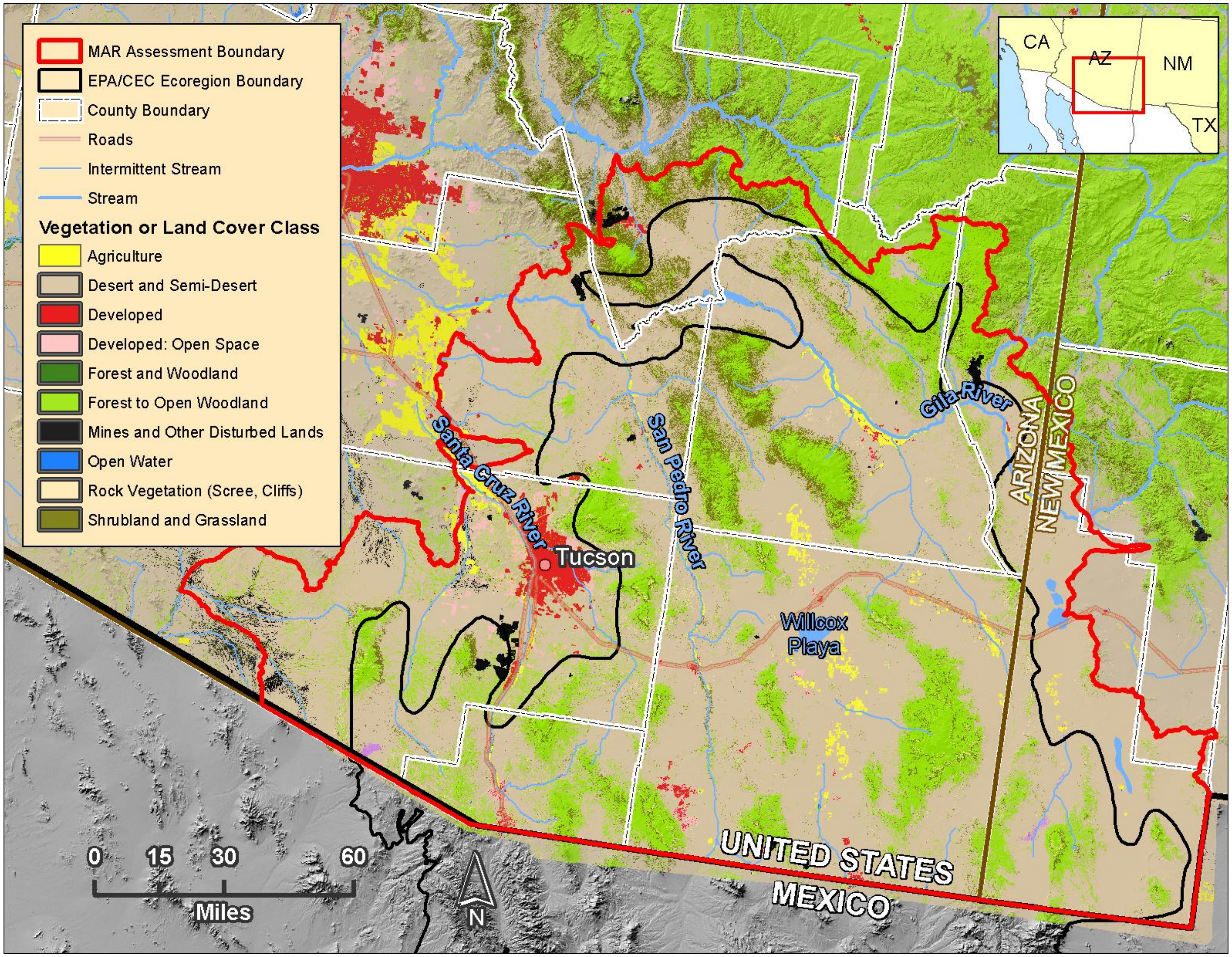
4.4.1 Ecosystems

A great diversity of biological communities and ecosystems occur in the Madrean Archipelago ecoregion. Brown (1982) provides a valuable overview of the biotic communities found in southwestern North America, including listings of both plants and animals found in the major vegetation types of this region. The uplands vary from desert scrub or shrublands in the warmest and driest areas to the spruce-fir forests found in small areas at the highest elevations of a few of the mountain ranges (Brown 1982, Mau-Crimmins et al. 2005). The wetlands and riparian areas vary from montane streams feeding into low-elevation rivers lined with deciduous trees and shrubs, to intermittently flooded playas, and emergent marshes and ciénegas associated with springs.

Below are brief, generalized descriptions of the major upland and wetland ecosystems, starting with the lowest elevation desert scrub and continuing upwards in elevation zones into the sky islands, followed by descriptions of the wetland ecosystems. They are organized by the conceptual model system divisions of Valley Uplands, Montane Uplands, and Streams and Wetlands. Much of the material has been drawn from Brown's (1982) overview of the biotic communities of the southwest.

Figure 4-12 shows a map of the vegetation classes present in this ecoregion, as mapped by the SW ReGAP effort. These classes are part of the hierarchical U.S. National Vegetation Classification (Anderson et al. 1998, Grossman et al. 1998); individual ecological systems considered for CEs in this REA are linked to these coarser classes. Because the ecological systems represent a finer-scale unit in the classification hierarchy, the coarser vegetation classes provide a simple, broad overview of the spatial pattern of vegetation in the U.S. portion of the ecoregion.

Figure 4-12. Map of vegetation classes and other land cover types present in the Madrean Archipelago ecoregion. Ecological systems can be grouped into broader classes in the U.S. National Vegetation Classification (Anderson et al. 1998, Grossman et al. 1998); those classes are shown here, in addition to other land uses, from NatureServe's (2013) data set. In this particular ecoregion, the non-specific disturbed lands class is primarily open-pit mines and is labeled accordingly.



VALLEY UPLANDS

Desert Scrub and Thornscrub

Aridity is the primary determinant of desert vegetation; in the Madrean Archipelago, desert scrub is the driest biotic community and found in the lowest elevations. Net primary productivity is relatively low, although lifeform diversity is high. The plants tend to be widely spaced and typically exhibit leaf adaptations to the hot, dry climate. In the Madrean Archipelago ecoregion, there are two major types of desert scrub: the Sonoran Palo Verde-Mixed Cacti scrub found on the periphery in the western portions, and the Chihuahuan Creosotebush scrub found throughout much of the ecoregion. Important species include acacias (*Acacia* spp.), palo verdes (*Cercidium* spp.), giant saguaro (*Carnegiea gigantea*), and creosote bush (*Larrea tridentata*). Succulents are very common in desert scrub, and to a lesser degree, thornscrub, with agave (*Agave* spp.), yucca (*Yucca* spp.), barrel cactus (*Ferocactus* and *Echinocactus* spp.), hedgehog cactus (*Mammillaria* spp.), and prickly pear and cholla (*Opuntia* spp.) among the most common. Warm- and cool-season annuals, both native (e.g., *Plantago patagonica*) and introduced (e.g., *Bromus rubens*), are common following rainfall. These desert scrub communities are not fire-adapted; the large spacing between plants limits the spread of fire across the landscape. Widespread fire was, therefore, historically a relatively rare occurrence in these communities.

Semi-desert Grasslands

In contrast to the Great Plains to the east, grasslands in the Madrean Archipelago ecoregion are generally semi-desert in nature, although species common in the Great Plains do occur here. These grasslands are typically composed of perennial short- and mid-grass species; annuals and geophytes are also common, with occasional shrubs or trees. Most grasses in semi-desert grasslands use the C4 photosynthetic pathway that provides greater water use efficiency than the C3 photosynthetic pathway of most other plants. Important species in the semi-desert grasslands of this ecoregion include black grama (*Bouteloua eriopoda)*, tobosa (*Pleuraphis mutica*), sideoats grama (*Bouteloua curtipendula)*, blue grama (*Bouteloua gracilis)*, plains lovegrass (*Eragrostis intermedia)*, sand dropseed (*Sporobolus cryptandrus*), vine mesquite (*Panicum obtusum*), curly mesquite *(Hilaria belangeri)*, ephedra (*Ephedra* spp.), sotol *(Dasylirion* spp.), yucca (*Yucca* spp.), ocotillo (*Fouqieria splendens*), many different cacti, and agave (*Agave* spp.). Fire is a relatively common and necessary occurrence in semi-desert grassland, historically burning every five to ten years (Gori et al. 2012, Gori and Enquist 2003). Fire maintains the open structure of the ecosystem, conferring a competitive advantage to graminoids over most woody plants. Fire suppression, intensive grazing, and soil erosion have degraded much of the grassland ecosystem in this region, leading to encroachment by woody species (mesquite, *Prosopis* spp.) and drought-resistant, non-native grasses such as Lehmann's lovegrass (*Eragrostis lehmanniana*) and Boer lovegrass (*Eragrostis curvula),* which were originally introduced to the ecoregion for forage and erosion control. Grassland ecosystems in the Madrean Archipelago have been recognized for their regional biological value, especially for grassland birds (Latta et al. 1999). In the MAR ecoregion there are a diversity of birds associated with grassland habitats that depend on this habitat for different aspects of their life histories, including overwintering, migration stopover, and breeding.

MONTANE UPLANDS

Chaparral

Chaparral is a semi-arid, shrub-dominated biotic community that occurs on the west coast of every continent between 30^{o} and 40^{o}N latitude. Chaparral in the interior southwestern U.S. is found along the Mogollon Rim and south into the lower montane zones of many of the sky islands, and Sierra Madre Occidentale of Mexico (Brown 1982, DeBano 1999). Chaparral shrub species have thick, sclerophyllous leaves containing large quantities of volatile compounds, and have a natural fire regime of intense, fast-moving fires that are often stand replacing. These fire-adapted shrub species sprout vigorously following fire, either from root crowns or from seed banks. The chaparral of the Madrean Archipelago ecoregion is less diverse than the coastal chaparral of California and is composed of dense stands of manzanita (*Arctostaphylos* spp.) and shrub live oak (*Quercus turbinella*), and Toumey oak *(Quercus toumeyi),* with mountain mahogany *(Cercocarpus montanus),* desert ceanothus *(Ceanothus greggii),* buckthorn (*Frangula betulifolia)*, *Purshia* spp., and silktassel (*Garrya* spp.) also present (Carmichael et al. 1978, DeBano 1999).

Madrean Evergreen Woodland
The transitional elevations between semi-desert grassland and the higher-elevation, conifer-cloaked mountains are dominated by Madrean evergreen woodlands. Madrean evergreen woodland is ubiquitous at middle elevations throughout the Madrean Archipelago ecoregion. There are three ecosystems comprising these woodlands: the "encinal" or oak-dominated woodlands; pinyon-juniper woodlands; and lower to mid-montane woodlands of pines, firs, and oaks. The Madrean encinal is characterized by evergreen oaks with thick, sclerophyllous leaves, such as emory oak (*Quercus emoryii*), Arizona white oak (*Quercus arizonica*), gray oak (*Quercus grisea),* silverleaf oak *(Quercus hypoleucoides),* netleaf oak *(Quercus rugosa)*, and Mexican blue oak (*Quercus oblongifolia)*. The Madrean pinyon-juniper woodlands are comonly mixes of pinyon pine species such as Mexican pinyon *(Pinus cembroides),* border pinyon (*Pinus discolor),* or two-needle pinyon (*Pinus edulis)*. The juniper species include red-berry juniper *(Juniperus coahuilensis)* and alligator juniper *(Juniperus deppeana)*. At higher elevations, the oak species mix with Arizona pine (*Pinus arizonica),* Apache pine *(Pinus engelmannii),* Chihuahuan pine *(Pinus leiophylla),* Ponderosa pine *(Pinus ponderosa)*, or southwestern white pine (*Pinus strobiformis).* In places, Douglas-fir (*Pseudotsuga menziesii)* is mixed with the pines and oaks, while Coahuilan fir (*Abies coahuilensis)*, corkbark fir (*Abies lasiocarpa* var. *arizonica*), or white fir (*Abies concolor)* occur in cooler or more mesic settings. Understory grasses and forbs are usually abundant. In general, the Madrean evergreen woodlands are fire-adapted ecosystems; although fire regimes may vary between woodland types, generally they experience frequent, low-intensity fires (Kaib et al. 1996, Schussman 2006).

Coniferous Forests
Dominated by conifers such as pines (*Pinus spp.*), spruces (*Picea spp*.), and firs (*Abies spp.*), coniferous forest occurs in the coolest settings of the Madrean Archipelago. These forests are confined to cooler sites (a function of elevation, aspect, and local geomorphology), generally upslope from the mixes of conifers with evergreen oaks. Most of the conifer forests in the sky islands are dominated by Douglas-fir (*Pseudotsuga menziesii*) and true firs (*Abies* spp.), with spruce (*Picea* spp.) at the highest elevations. These fire-adapted conifer forests have a range of fire regimes, from low-intensity fires occurring every nine to fifteen years in ponderosa pine and mixed-conifer forests (Dimmitt 2000), to very infrequent, stand-replacing fires every 150 to 300 years in the spruce-fir forests at the highest elevations (Margolis et al. 2011).

Temperate Deciduous Forests
Although relatively minor in the Madrean Archipelago ecoregion, temperate deciduous forests are found here and are characterized by cold-tolerant, deciduous, woody plants such as Gambel oak (*Quercus gambellii*), trembling aspen (*Populus tremuloides*), and maples and box elder (*Acer* spp.). These typically occur in micro-climates at high elevations in the sky islands, often on north-facing slopes, and are interspersed with coniferous forest. Cold-tolerant deciduous species are often found in the understory of coniferous forests as well.

STREAMS AND WETLANDS
Freshwater ecosystems are critical components of the Madrean Archipelago's biodiversity. Although occupying only a small proportion of the landscape (<1% of the ecoregion), they support a disproportionately high number of species. Rivers, streams, marshes and ciénegas, and ephemerally wet playas each support a rich diversity of plant and animals species. Riparian corridors along the streams

provide migratory birds and pollinating insects and bats with critical travel corridors and resources. Large-scale migrations of waterfowl, shorebirds, raptors, and cranes depend upon shallow playa waters as migratory stopovers. Willcox Playa, Lordsburg Playa, and the upper San Pedro River are critical links for birds on both northern and southern migration routes. Perhaps the critical stopover hotspot of the ecoregion is the riparian woodland of the upper San Pedro, which serves as a corridor for up to four million neotropical migrants and is also important for nesting and wintering habitat. Locally, riparian woodlands help regulate other processes, such as river temperature, flooding intensity, soil retention, and evaporation rates.

Riparian Areas
Riparian corridors and their associated perennially or seasonally flowing streams occur along canyons and across desert valleys of the southwestern United States and adjacent Mexico. Mesquite-dominated (*Prosopis* spp.) sites can also occur along intermittent streams, where higher groundwater levels permit. The vegetation is a mix of riparian woodlands and shrublands, with reaches of herbaceous communities intermixed. Dominant native trees include Fremont's cottonwood (*Populus fremontii*), velvet mesquite (*Prosopis velutina*), Gooding's willow (*Salix gooddingii*), and sycamores (*Platanus racemosa*). Native shrubs include arroyo willow (*Salix lasiolepis*), Geyer's willow (*Salix geyeriana*), seepwillow (*Baccharis* spp.), silver buffaloberry (*Shepherdia argentea*), and coyote willow (*Salix exigua*). Stream reaches alternate between perennial and intermittent flow depending on local alluvial and groundwater patterns as well as local water use. Varying patterns of flooding and drought change the composition and structure of the riparian vegetation and the distribution of aquatic habitats (deep and shallow pools, shading from banks, water temperature and chemistry, extent of the wetted gravel zone and other characteristics); these patterns are driven by the natural timing and amount of flushing flows following winter and summer storms. Over the past century (1900s), the invasion of non-native species such as tamarisk and the increase in native woody species have changed the ratio of woody to herbaceous communities along riparian corridors (Stromberg et al. 2009). Higher-elevation riparian reaches flowing out of the sky islands are typically characterized by bedrock channels, shallower alluvial soils, and lush riparian vegetation, in stark contrast to the adjacent, upslope desert scrub. Cottonwoods (*Populus* spp.) and willows (*Salix* spp.) are common, as well as oaks (*Quercus* spp.), ash (*Fraxinus* spp.) and wingleaf soapberry (*Sapindus saponaria*). Other shrubs include chokecherry (*Prunus virginiana*), alder (*Alnus* spp.) and arroyo willow (*Salix lasiolepis)*. Upper-elevation riparian corridors are an important link between the orographically wetter mountains and the lower, larger riparian reaches, and serve as critically important movement corridors for mammals.

Playas
Playas are closed, shallow drainage pockets or basins that experience intermittent flooding from surface runoff and, in some instances, from shallow groundwater discharge. They are typically barren of vegetation for much of the year or even multiple years. Soils are fine and salt crusts are common, with small saltgrass (*Distichlis spicata*) and alkali sacaton grass (*Sporobolus airoides)* beds in depressions and sparse shrubs around the margins. Large playas found in the Madrean Archipelago ecoregion include Willcox Playa and Lordsburg Playa. Wetting occurs primarily through runoff combined with on-site precipitation, where clay soils or hardpans prevent most downward percolation, although high groundwater levels may have historically contributed to wetting the playas. Madrean Archipelago playas are ecologically distinct from other types of MAR wetlands in three ways: First, they support a diverse and seasonally changing assemblage of birds, with winter numbers > 5,000 at Willcox Playa alone. During the winter they provide roosting and feeding habitat for large numbers of sandhill cranes and smaller numbers of water birds such as killdeer, snipe, and white-faced ibis, particularly in wet winters. Second, the playas in this ecoregion support a rich and unique assemblage of macroinvertebrates, including some 400 beetle genera from Willcox Playa, and tiger beetles specially adapted to the alkaline

chemistry. Numerous crustaceans – particularly branchiopods – are also found here and emerge during wet episodes, providing key food resources for water birds. Third, the playas support several rare plant species.

Ciénegas, Springs, and Marshes
Ciénegas are spring-fed marshes typically composed of lush herbaceous vegetation surrounding pools of water. Ciénegas are sustained by permanent, rarely fluctuating sources of water (springs), and are near enough to headwaters that the probability of scouring from floods is minimal. In shallow pool margins, emergent plants include species of spikerush (*Eleocharis* spp.), sedge (*Carex* spp.) and rushes (*Juncus* spp.). Taller marsh vegetation can be found in adjacent deeper waters, such as cattails (*Typha* spp.), bulrush (*Schoenoplectus* spp., *Scirpus* spp.) and common reed (*Phragmites australis*); all of these species are native to the southwest. Relatively deep water may have floating and submerged aquatic plants. Ciénegas may be ringed by saline soils due to capillary action and evaporation, where salt-grass and alkali sacaton (*Sporobolus airoides*) may be abundant. Ciénegas tend to have deep organic soils and are very productive ecosystems. The sky island geologic faults provide for groundwater recharge along fault lines and are the source for springs and seeps, two important settings for ciénega creation and maintenance. Ciénegas were once much more abundant in the ecoregion, and are now reduced to a small fraction of their former distribution, due to greatly lowered water tables resulting from a complex interaction of drought and increased human and livestock use in the past century (Hendrickson and Minckley 1984). They generally occur as isolated wetlands along the sides of valley floors, separated from the main stream channel, although areas of springs and marsh vegetation do occur within the active channel of the lower San Pedro and other rivers.

4.4.2 Species Diversity

The Madrean Archipelago has exceptional species richness owing to its complex physiography and its location at the nexus of the Californian, Sonoran, Intermountain, Cordilleran, and Sierra Madrean provinces (Warshall 1995). Many plant and animal species are at the edges of their ranges in this region, particularly tropical species such as trees, orchids, moths, birds and bats (Felger and Wilson 1995), with a high number of endemic as well as threatened and endangered species (Warshall 1995). At least 468 species of birds have been documented in southeastern Arizona in the past 50 years, with approximately 207 species known or thought to breed here, along with 240 butterfly species, and hundreds of species of wood-rotting fungi (Bailowitz and Brock 1991, Corman and Wise-Gervais 2005, Edison et al. 1995, Gilbertson and Bigelow 1998, Marshall et al. 2004). More than 4,000 species of vascular plants and 110 species of mammals, including 23 bat species, have been documented (Felger et al. 1997, Schmidt and Dalton 1995, Simpson 1964). Southeastern Arizona has the greatest mammalian diversity north of Mexico (Turner et al. 1995). This is twice the mammal diversity of Yellowstone National Park and includes narrowly endemic species such as the white-sided jackrabbit (*Lepus callotis*), the Arizona cotton rat (*Sigmodon arizonae*), the Mearn's pocket gopher (*Thomomys bottae mearnsi*), and species at the edges of their ranges such as jaguar (*Panthera onca*) and ocelot (*Leopardus pardalis*). Large mammals with extensive geographic ranges that inhabit this ecoregion include black bear (*Ursus americanus*), mountain lion (*Puma concolor*), bighorn sheep (*Ovis canadensis*), and pronghorn (*Antilocapra americana*). The New Mexico Department of Game and Fish identifies 102 Species of Greatest Conservation need in the New Mexico portion of the MAR ecoregion (NMDGF 2006).

To further illustrate the relative diversity of the ecoregion, at the heart of the MAR in the Peloncillo Moutains of southeastern Arizona and southwestern New Mexico, there are more species of amphibians and reptiles than in any other single mountain range in New Mexico, representing 72% of the 123 species known to occur throughout New Mexico, and Antelope Pass boasts the highest lizard diversity of any comparably-sized area in the U.S. Despite the aridity of this region, this count includes 14 native amphibians (Bodner et al. 2006). In the Arizona portion of the MAR, there are 11 species of amphibians of the 25 known to occur throughout Arizona and 76 species of reptiles, or 71% of the 107 known to occur throughout Arizona (Brennan and Holycross 2006). Insect diversity is largely unexplored but almost 400 species of bees are known from the San Bernardino NWR, with 1,000 species estimated to reside in the Peloncillo Mountain region alone (Bodner et al. 2006). A total of 246 species of skippers and true butterflies have been recorded in southeastern Arizona (Bailowitz and Brock 1991). The MAR is also home to a myriad of narrowly endemic talus and spring snails, and a high number of neotropical butterflies.

4.5 Ecological Integrity

Characterizing the ecological integrity for the ecoregion as a whole is a key component of the REA. Ecological integrity is defined as the ability of the region's ecosystems to maintain their species composition, structure, spatial patterns or distribution, and ecological functions and processes within natural or acceptable ranges of variation.

The ecoregional conceptual model provides the foundation for defining ecological integrity. As indicated in the ecoregional conceptual model, the natural features, processes, or drivers that are most important in shaping the biodiversity of the Madrean Archipelago, and are key determinants of ecological integrity, include the following:

- Elevational gradient
- Biogeography (nexus of the ecoregion between tropical and temperate)
- Physiography: the basin and range (or sky island and desert seas) topography
- Climate patterns: temperature, timing and patterns of precipitation
- Hydrologic regime
- Fire regime
- Connectivity (relating to basin and range topography)

The elevational gradients and landforms (basin and range topography, with ranges fairly isolated from each other) in conjunction with climate and soils are critical determinants of the overall type and distribution of ecosystems in the ecoregion. Biogeography plays an important role in the particular mix of species found in the ecoregion and is a key reason for the high level of species diversity found in this ecoregion. Fire is a key process in many of the upland ecosystems, further refining the species composition and vegetative structure of these systems; by removing vegetation in key areas of a watershed, fire can also influence certain aspects of hydrologic regimes (i.e., surface flows). Hydrology, which is primarily determined by the region's climate (precipitation patterns) and landforms, is the main process driver in the aquatic and wetland ecosystems of the region. Of these biophysical controls and ecological processes, the physiographic characteristics (elevation, landforms) and biogeography are immutable; these characteristics would not be evaluated as part of the assessment of ecological integrity. Climate, hydrology, fire regimes, and soils, on the other hand, may change in response to either natural or anthropogenic influences. Changes in these key variables can then be expected to alter the composition, structure, spatial patterns, and ecological functions of the region's ecosystems. Therefore, the assessment of ecological integrity will address these variables in some fashion.

Following the approach used for individual ecological system CEs (see the CE conceptual models in **Appendix C**), for assessment purposes ecological integrity of the ecoregion can be defined by a series of Key Ecological Attributes (KEAs), which are based on the driving variables listed above, or the resulting expression of these variables through the pattern and composition of the ecological systems themselves. Table 4-1 summarizes proposed Key Ecological Attributes and some possible indicators for informing the assessment of ecological integrity.

Table 4-1. List of possible Key Ecological Attributes (KEAs) and indicators for ecological integrity of the ecoregion.

KEA Category	KEA	Potential Indicators
Ecosystem Processes	Climate	• Temperature alterations • Precipitation alterations
	Hydrology/Climate	• Hydrologic alterations associated with precipitation alterations due to altered climate
	Hydrology	• Water withdrawals for human uses (municipal, industrial, agriculture) • Historical downcutting – altered flow and extent of certain wetlands
	Fire	• Fire regime condition classes (FRCC)
Ecosystem Context	Connectivity	• Overall landscape permeability • Fragstats calculation of edges or patchiness (comparing natural vs. non-natural)
Ecosystem (Biotic) Condition	Percent natural cover	• % converted to development or agriculture
	Landscape condition	• Index, across landscape of on-site and off-site impacts, on condition, resulting from various development features and other infrastructure and land uses
	Condition of ecological systems	• % grazed at x% utilization
	Native species composition	• % covered or significantly affected by invasives
Ecosystem Extent (Size)	Ecosystem Size	• Index, across ecological system CEs, of how much of a shift there has been in extent of ecological systems relative to historical distribution (e.g., LANDFIRE PVT/EVT comparison if data were adequate for this ecoregion)

There are several options for assessing ecological integrity for the MAR ecoregion. Status assessment results for individual CEs could be combined across broad categories of CEs (e.g., uplands and aquatic systems/wetlands) and KEAs (e.g., size, condition, landscape context) to generate one or more indices of ecological integrity across the ecoregion – a "bottom-up" approach. An alternative approach would be to consider the natural drivers and features that are the key determinants of the ecoregion's biodiversity, as summarized by the KEAs above, and assess those factors independently of the CEs – a "top-down" approach. The methods for evaluating ecological integrity will be further developed in discussions with the BLM and the Technical Team.

5 Human Context

Anthropogenic influences are a critical component of the ecoregion conceptual model and are included in the conceptual diagrams in that section. Anthropogenic activities and uses of the ecoregion also shape the issues facing natural resource managers in the ecoregion. This section of the report therefore fills a dual purpose: providing a brief narrative description of the human context that illustrates the anthropogenic role in the ecoregion conceptual model and introducing the subsequent section on natural resources-related issues facing the ecoregion.

5.1 Demographic Overview

The human population in the ecoregional assessment area as a whole (shown in Figure 2-2 by yellow outline and international boundary) is estimated to be approaching approximately 1.2 million (compiled from ADWR 2010a, Community by Design 2011, and U.S. Census Bureau). In the U.S. portion of the ecoregion itself (shown in Figure 2-2 with solid green outline), the population is estimated to be under 200,000: the population of the surrounding Southeastern Arizona Planning Area was approximately 188,300 in 2000 (as compiled in ADWR 2010a), while Hidalgo County's was approximately 4,900 in 2010 (Community by Design 2011). It is generally concentrated in smaller municipalities, a number of which are located along the Interstate 10 or Interstate 19 corridors. Sierra Vista, Nogales (AZ) and Douglas are the largest municipalities within the U.S. portion of the ecoregion, with populations of approximately 44,000, 21,000, and 17,000 respectively. Other cities and towns in the ecoregion include Safford, Willcox, Benson, and Bisbee in the United States, and Nogales, Agua Prieta, Cananea, Magdalena de Kino, and Nacozari in Mexico (see also Figure 2-1). Population densities outside these areas are low, often below five people per square mile (Gorenflo 2003 as summarized by Marshall et al. 2004); for example, Hidalgo County has a density of 1.4 people per square mile (Community by Design 2011).

Lying in the far western portion of the larger ecoregional assessment area (shown in Figure 2-2 by the yellow outline and international boundary), Tucson, AZ is the largest city in the assessment area, with a population nearing one million in the greater metropolitan area. Tucson is the county seat of Pima County.

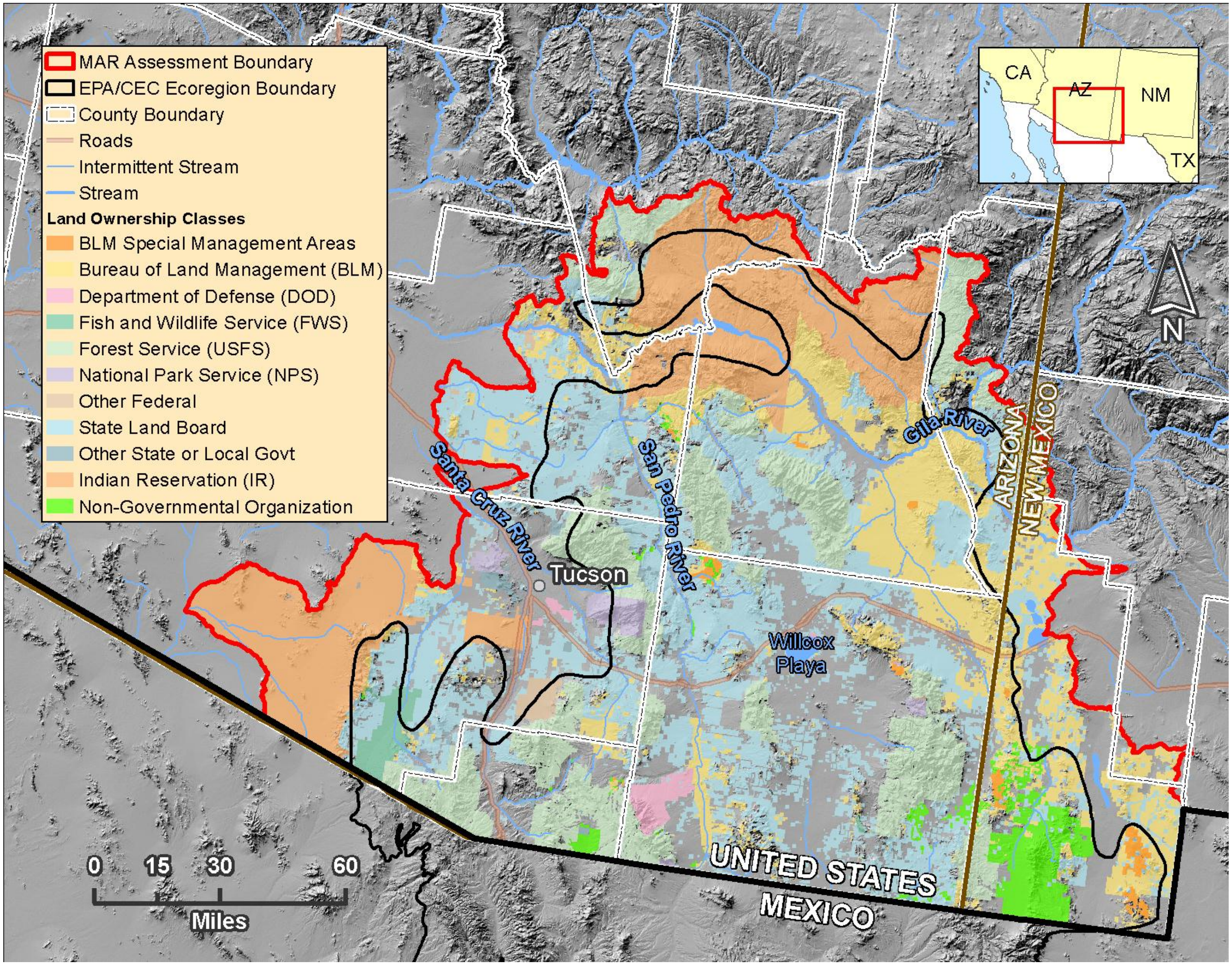
5.2 Land Ownership

As in most of the American West, the majority of the land in this ecoregion is in public ownership (Table 5-1). The patterns of land ownership are the result of historical European-American settlement patterns and government agency missions. Private lands tend to be concentrated in the valleys along waterways, in part due to the proximity of water in such settings. U.S. Forest Service lands are located in the sky islands – the mountain ranges that are home to the forest ecosystems in this region; land above approximately 4,000 feet in elevation is generally National Forest. The foothills and lower elevations between the sky islands and the river valleys are predominantly managed either by the Bureau of Land Management or by Arizona's State Land Board. Buenos Aires National Wildlife Refuge is the largest USFWS refuge in the ecoregion. The Tohono O'odham Nation Reservation covers a significant area in the southwestern portion of the Madrean assessment area, and the San Carlos Apache Nation Reservation covers a large portion of the north central part of the ecoregion. The San Xavier District of the Tohono O'odham Nation is on a separate land unit lying to the east of the main area of the Tohono O'odham Nation. The Animas Foundation, which is part of the Malpai Borderlands Group, manages the 321,000-acre (129,900 ha) Diamond A Ranch in the New Mexico portion of the ecoregion. Two large military facilities are located in this ecoregion as well: Fort Huachuca, near the Arizona-Mexico border, and the Willcox Dry Lake Bombing Range on the Willcox Playa. Typical ranching operations are usually comprised of a small area of private land (on the order of 40-160 acres (16-65 ha)) where the ranch is headquartered and contiguous grazing allotments that are leased from federal or state agencies. The broad ownership patterns of this ecoregion are illustrated in Figure 5-1; ownership information is from the USGS' Protected Areas Database of the United States (PAD-US), version 1.3 (USGS 2012). Areas with no ownership information, such as the Willcox Basin around the Willcox Playa, are assumed to be in private ownership.

Table 5-1. Percentage of the Madrean Archipelago ecoregional assessment area in major categories of land ownership. Based on USGS' Protected Areas Database, v.1.3

Land Owner Type	Percentage of Madrean Archipelago assessment area
Federal	41.5%
State	26.5%
Native American	29.7%
NGO	2.6%

Figure 5-1. Map illustrating land ownership in the Madrean Archipelago ecoregional assessment area. Map is based on USGS' Protected Areas Database of the United States (PAD-US), version 1.3 (USGS 2012). Land not otherwise designated is assumed to be privately owned.



5.3 Land Uses

The predominant land use in the Madrean Archipelago in terms of spatial extent is cattle grazing; public lands which are not otherwise designated for conservation are generally rangeland. Although estimated to occupy less than 1.5% of the ecoregion (based on LANDFIRE vegetation/land cover data), agriculture is another important land use in this ecoregion; agricultural lands have replaced critical riparian and other lowland habitat and are responsible for a significant portion of cultural water use in the ecoregion. Tucson is the largest metropolitan area in this ecoregion, with smaller municipalities and other developed areas also present. A relatively sparse network of transportation and utility corridors span the ecoregion. Mining is the largest industrial land use in this ecoregion; open-pit copper mines and other large mines appear as substantial areas of “mines and other disturbed land” in Figure 4-12. These anthropogenic land uses and associated activities give rise to or are the direct cause of the change agents that are affecting ecological systems and their driving or supporting processes; these land uses and associated CAs are discussed in detail in the Current Issues chapter.

6 Current Issues in the Madrean Archipelago Ecoregion

The Madrean Archipelago ecoregion faces many issues relating to its natural resources as a result of the interplay between human activities and influences and the physical and ecological processes shaping the ecoregion. These issues have been summarized in a variety of reports and publications, such as the Heinz Center report on climate change and Arizona wildlife (Heinz Center 2011b), volume 3 of the Arizona Water Atlas (ADWR 2010a), the chapter on this ecoregion in the New Mexico Comprehensive Wildlife Strategy (NMDGF 2006), USGS' publication on U.S.-Mexico borderlands (Updike et al. 2013), and expanded upon in more detail in publications such as the periodic Sky Island/Madrean Archipelago conference proceedings (DeBano et al. 1995, Gottfried et al. 2013, Gottfried et al. 2005). Issues summarized in these reports were also identified in various forms in the REA Development Forums and include the following:

- Climate change
- Water availability
- Invasive species
- Encroachment of woody species
- Altered fire regimes and fire suppression
- Livestock grazing
- Border control activities and infrastructure
- Development (residential, industrial, utilities, etc.)
- Agriculture

These issues inform the change agents (CAs) that will be assessed in this REA. For the purpose of having a standard terminology for and shared understanding of the CAs, the issues identified as being critical to this REA are organized into the four broad categories of CA that are standard for BLM REAs:

1. Climate Change
2. Invasives
    - Non-native, invasive species
    - Managed non-native species
    - Native woody increasers
3. Fire
4. Development
    - Urban/suburban, commercial, industrial development
    - Roads

- Utilities
- Mining
- Energy development
- Agriculture
- Livestock grazing
- Border-related infrastructure, including barriers, roads, lighting, and related features
- Water usage associated with these activities or infrastructure

The crucial and over-arching issue of water availability is not categorized as its own CA – it is instead reflected within the Development and Climate Change categories. Cultural water use associated with development (e.g., agricultural, municipal, and industrial uses), in conjunction with projected alterations in timing and quantity of precipitation under climate change, are the forces – or CAs – shaping water availability. Regardless of how they are categorized, water availability and hydrologic issues will be a key area of assessment in this REA.

These issues and their impacts on the region's natural resources are broadly summarized in the following sections in this chapter; each section concludes with a synthesis of the specific management concerns identified by REA participants around these issues. Note that all of these issues interact with and influence each other to varying degrees, so there is some overlap between the summaries of each of the issues. More details on the specific effects of each of these change agents on individual conservation elements are included in the conceptual models for each of the CEs (see **Appendices C** and **D**).

6.1 Climate Change

The Madrean Archipelago is located in a part of the U.S. that is projected to be a climate change "hotspot" (Kerr 2008), with significant impacts expected throughout the ecoregion. The projected increased temperatures and altered precipitation patterns are expected to have numerous severe effects, notably on water availabilitiy in this arid ecoregion. The Heinz Center (2011b) developed a report summarizing projected climate change impacts for the state of Arizona, based on their review of numerous studies. Although focused on Arizona as a whole, the impacts are applicable specifically to the Madrean ecoregion as well. The summary of climate change issues for the Madrean Archipelago ecoregion is based substantially on the Heinz Center (2011b) publication, with additional sources incorporated in some areas.

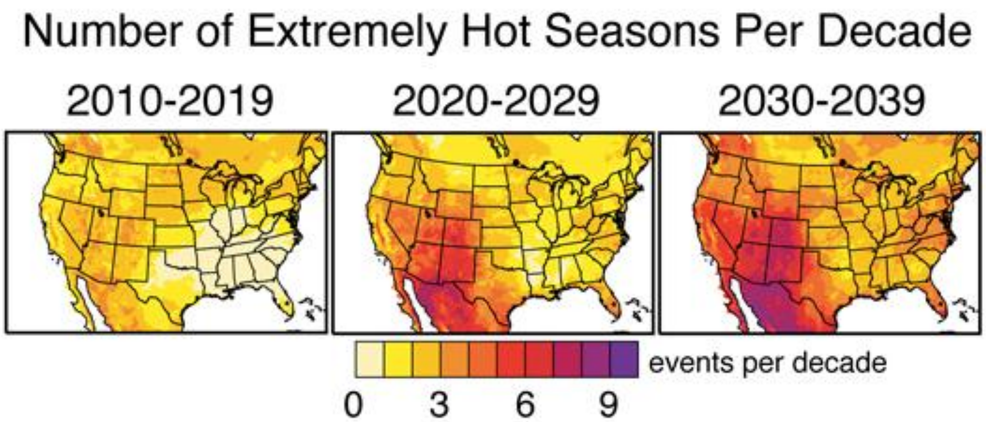
In general, a warmer, drier climate is projected for the southwestern U.S. over the 21st century, and these trends are already being observed (Archer and Predick 2008, Dominguez et al. 2009, Heinz Center 2011a, Heinz Center 2011b, IPCC 2007, Seager et al. 2007, USGCRP 2009). These trends and projections apply to the Madrean Archipelago; specific projections and associated impacts are summarized below. For more specifics on on-going or potential climate change impacts on individual CEs, see the CE conceptual models (in **Appendices C** and **D**) associated with this report.

6.1.1 Warming Temperatures

As summarized by the Heinz Center (2011b), the southwestern U.S. is warming significantly more than the global average, rising over two degrees Fahrenheit in Arizona specifically (AZ FRTF 2010)., compared to a global average increase of one degree F over the last 150 years (IPCC 2007, USGCRP 2009). The southwestern U.S. is projected to continue warming at a faster rate than most of the U.S., with most warming taking place during summer months. The western U.S. is expected to warm an additional 3.6 to

9 degrees F during summer by 2040 to 2069, with the most extreme scenario predicting a 14-degree F increase by 2100 (AZ CCAG 2006). Extremes in high temperatures are projected to become increasingly common over the next 30 years, particularly in the southwestern U.S. (Archer and Predick 2008, Diffenbaugh and Ashfaq 2010; Figure 6-1). Warmer temperatures are also expected to affect precipitation, as described below.

Figure 6-1. Map showing projections of the number of extremely hot seasons per decade across the United States for the 2010s, 2020s, and 2030s (from Diffenbaugh and Ashfaq 2010). The Madrean Archipelago ecoregion is among the areas in the southwestern U.S. projected to have the highest numbers (7-9) of extremely hot seasons in upcoming decades.



6.1.2 Changes in Precipitation

Compared to temperature predictions, model projections for precipitation are more variable. Nonetheless, scientists generally expect the following types of critical changes in the quantity, pattern (duration, timing, frequency), and type (i.e., rain vs. snow) of precipitation in the southwestern U.S., including the Madrean:

- Decreased total annual precipitation
- Decreased snowfall, increased winter rain, and earlier, faster snowmelt
- Increased frequency of high-intensity storms during summer

Decreased total annual precipitation

Approximately 60% of the MAR's precipitation comes during the wet monsoon season; most of the remainder comes from winter snow or rain (as illustrated earlier in Figure 4-2). Recent long-term trends already show decreased rainfall in the southwestern U.S. (Seager et al. 2007). As summarized in the Heinz Center report (2011b), between 2002 and 2010, two of the driest years in a century and two of the lowest levels of run-off ever were recorded for the state of Arizona (AZ CCAG 2006). Lack of monsoonal rains in the Southwest (also observed in the MAR) during 2009 contributed to Arizona's fifth-driest year and third-driest summer in recorded history (Arndt et al. 2010). Following these recent trends, total annual precipitation is also projected to decrease in the future (Christensen et al. 2007, Dominguez et al. 2009). Complicating effects of climate change are changes in oceanic circulation and regional wind patterns, which may decrease the amount of atmospheric moisture being delivered inland to the MAR. Dry seasons are projected by over 90% of the regional climate models to be increasingly drier in many regions of the globe, including the southwestern U.S. (Solomon et al. 2009) and therefore the Madrean Archipelago ecoregion; there is greater agreement among models that precipitation during the dry season will decrease compared to model projections for the wet months (Christensen et al. 2007, Dominguez et al. 2009).

Decreased snowfall, increased winter rain, and earlier, faster snowmelt
In general, there is expected to be less winter snowfall, more winter rain, and a faster, earlier snowmelt in Arizona's mountains (AZ CCAG 2006). Trends over the last 50 years show earlier spring snowmelt and declining winter snowpack (AZ FRTF 2010). As summarized in the Heinz Center report (2011b), montane areas may see less snowfall and more rain in the winter due to changes in the spatial patterns of precipitation as well as warmer temperatures at higher elevations. In addition, warmer temperatures may lead to earlier snowmelt, which would alter peak runoff in streams and rivers, may result in higher magnitude floods (AZ CCAG 2006), and may result in streams becoming intermittent earlier in the season, with an increase in the spatial extent of intermittent stream reaches in summer months (USCCSP 2009, Solomon et al. 2009).

Summer-time decadal trends showing abrupt shifts in flood type – that is, loss of peak flows (annual floods) during the summer – have been observed in the San Pedro River over the twentieth century (Hirschboeck 2009). Since 1965, peak flows have more often been produced by winter storms and less frequently by summer convective storms. The same trend has been documented in the Santa Cruz River. The reason for this shift is under debate, but some research points to an increase of the frequency and strength of El Niño years that may explain the trend toward increased precipitation in winter months (Hirschboeck 2009). In addition to receiving less total precipitation annually, this change in timing and magnitude may shift the timing of flood events (Hirschboeck 2009).

Increased frequency of high-intensity storms during summer
As summarized in the Heinz Center report (2011b), high-intensity storms are like to become common in the southwestern U.S. during summer months. Paired with increased summer temperatures, this will result in longer dry periods interrupted by occasional, intense rain storms, resulting in more frequent erosive events and an increase in the likelihood of flash flooding (Archer and Predick 2008).

6.1.3 Climate Change-Related Stressors

Climate change effects interact with each other, and with other stressors such as altered fire regimes and invasive species, often intensifying and furthering the effects of one or more stressors. Some of the major impacts predicted to affect the biodiversity of the Madrean Archipelago are summarized below, based on the Heinz Center report for Arizona (2011b).

Drought
While the ecoregion has historically experienced drought, modeling shows that droughts will occur with higher temperatures and greater frequency, thus becoming more severe (USGCRP 2009). Droughts deplete soil moisture, stress vegetation, increase vegetation susceptibility to insect and disease infestations and associated die-off, and can result in intensified fires and degraded wildlife habitat (SWCCN 2008). Droughts are projected to increase in frequency in this ecoregion (as well as Arizona as a whole) (Heinz Center 2011b, AZ CCAG 2006). The effect of drought on ecosystems and species will be cumulative with other human-induced impacts such as land use changes, invasive species, and habitat fragmentation.

Flooding
Winter and monsoonal precipitation in Arizona is becoming increasingly variable, trending towards more frequent cycles of extremely dry and extremely wet seasons (USGCRP 2009). Shifts in the timing of the monsoon may potentially affect species and ecosystems that are adapted to the seasonal patterns of monsoonal rainfall. As summarized by the Heinz Center (2011b), a shift from less snowfall to more rainfall in winter months, combined with earlier and increased snowmelt in mountain regions like the MAR, can also cause an increased risk of flooding and erosion from flooding (USGCRP 2009). Increase in the number and severity of wildfires may lead to more intense runoff during rainfall events, and may

further increase flooding and soil erosion. The following section in this chapter, **Water Availability and Altered Hydrology**, expands on the issue of changes in flooding.

Reduced Water Supply and Availability

Water resources are predicted to be reduced due to climate change in many arid and semi-arid regions, including the MAR (IPCC 2007b). As summarized by the Heinz Center (2011b), the Southwest is one of the few regions of the world where there is consistent agreement among climate models that there will be reduction in water sources (Dominguez et al. 2009, see also Christensen et al. 2007). Higher temperatures, changes in precipitation, and increased water evaporation will lead to lower water levels in rivers and streams during summer months (AZ CCAG 2006). Increased evaporation will also affect processes including plant production and soil respiration (AZ CCAG 2006, Weltzin et al. 2003). Groundwater recharge is likely to decrease, presenting “a challenging scenario for an [ecoregion] whose population is already relying progressively more on groundwater withdrawals for irrigation and municipal water supplies” (Heinz Center 2011b). The following section in this chapter, **Water Availability and Altered Hydrology**, expands on this issue.

Wildfires

Madrean ecosystems have undergone the same fire suppression and overgrazing historically as other parts of the southwest and, as expanded on in the later **Fire** section in this chapter, are predicted to experience more frequent and intense wildfires under altered climate regimes due to increased fuel loading and increases in flammable invasive species (USCCSP 2009). Increased fire frequency and intensity can also be linked to climate change effects, including rising temperatures, spring snowpack reductions, changes in precipitation patterns, decreased soil moisture, and insect outbreaks that weaken trees and other vegetation (Heinz Center 2011b).

Invasive Species

Invasive species disrupt native ecosystems and biotic assemblages in a variety of ways, as discussed in the later section, **Species of Management Concern: Invasive Non-Natives, Managed Non-Natives, and Native Woody “Increasers”**, in this chapter. New species may become established, and invasive species already present in the ecoregion may thrive and spread. The continued expansion of buffelgrass and Lehmann’s lovegrass, exacerbated by climate change, is of substantial concern in this ecoregion. The likely increase or decline in tamarisk due to biocontrol efforts is of concern as well; this is also discussed in the later section on **Invasive Non-Natives**.

6.1.4 Climate Change and Ecosystems

Madrean ecosystems will undoubtedly be affected by climate change and its interactions with other stressors in a variety of ways. Studies project that plant species will tend to move upward in elevation and latitude in response to increasing temperatures (e.g., Kupfer et al. 2005), and Brusca et al. (2013) have confirmed that this is already taking place in the sky islands of this ecoregion. Although aquatic ecosystems of the region have evolved under high variability of temperature and water availability, the projected increase in harsher and lengthier droughts and reduced water availability will likely shift hydrologic regimes potentially beyond their threshold to adapt, leading to loss of some entire aquatic systems (Barnett et al. 2008, USCCSP 2009). As summarized by the Heinz Center (2011b), plant and animal species in arid regions such as the Madrean are already approaching physiological limits for water and temperature stress; as a result, even minor changes in precipitation, temperature, or the frequency and magnitude of current seasonal (e.g., monsoons) or extreme weather events could dramatically change their distribution, abundance, and composition (Archer and Predick 2008, McCluney et al. 2012, McKechnie and Wolf 2010).

Semi-desert Grasslands and Other Lower Elevation Systems

In semi-desert grasslands, invasive, non-native grasses may further displace native species under an altered climate, resulting in increasing expanses of non-native-grass-dominated grassland (Archer and Predick 2008). Gori and Enquist (2003) estimated that 22% of grasslands in the U.S. portion of the MAR are already dominated or heavily invaded by non-native lovegrasses (*Eragrostis lehmanniana* and *Eragrostis curvula*). In general, the semi-desert grasslands have the potential to expand upslope in response to increasing temperatures; whether it will be primarily non-native grasses expanding or mesquite-dominated former grasslands (or both) is unclear. Cactus species and cactus-dominated communities in the periphery of the MAR may be highly vulnerable to climate change-induced stressors, including disruption of inter-specific interactions (pollinators, habitat providers and herbivory) as well as mitigation-related human activities, such as development of solar arrays (Frances et al. 2011, Treher et al. 2012).

Riparian Systems, Streams and Rivers

The reduced availability of water will decrease the total area of streams, associated wetlands, and riparian areas and the amount of habitat they can provide, thereby creating substantial impacts on the wildlife and aquatic species dependent on these habitats. With increased frequency and intensity of drought, lowered water levels, and a transformed hydrologic regime, native riparian species are likely to be weakened, and aggressive invasives such as tamarisk have potential to expand; tamarisk in particular can thrive in areas with decreased groundwater (Archer and Predick 2008, Stromberg et al. 2009). These alterations are expected to reduce the abundance and richness of plant and wildlife species in these habitats.

As water temperatures increase, fish species in the desert Southwest will no longer have access to cooler waters into which to migrate. Habitat will also be affected through the surrounding vegetation's reaction to increased droughts. As the vegetation cover and stability of the soil changes, more soil and sediment will run off into the waters, affecting the water quality, riparian zone vegetation, and aquatic species (Stromberg and Tellman 2009).

Seasonal Wetlands (Intermittent Streams, Playas)

Reduced precipitation totals combined with increased frequency and intensity of drought and earlier snowmelt are expected to reduce the quantity and size of seasonally wet habitats such as playas and intermittent streams. In addition, the timing of the availability of these habitats may change as well. As highlighted by the Heinz Center (2011b), amphibians are an example of an entire group that may experience negative population impacts or local extinction if they cannot adapt their breeding patterns to this shift in timing or cannot sustain themselves through multiple dry years (USCCSP 2009).

Coniferous Forests

As summarized by the Heinz Center (2011b), coniferous forests of the southwestern U.S. are projected to become warmer and drier, experience more frequent water stress, undergo shifts in vegetation types and distributions, and potentially experience large forest die-offs (UCCSP 2009, Zugmeyer and Koprowski 2009), and these ecosystems are already approaching their climate-related threshold (USCCSP 2009). Increased drought combined with warmer temperatures has already been implicated in widespread forest die-offs and insect infestations in the southwestern U.S. (Breshears 2005, SWCCN 2008, USCCSP 2009, USFS 2004) Climate change is also projected to increase the frequency of outbreaks of bark beetles and other insect pests (Bentz et al. 2010), further contributing to forest die-offs.

6.1.5 Management Concerns Around Climate Change

Based on the pervasive and potentially extreme impacts of climate change, and the number of MQs identified that involve this issue, this change agent is a major issue for resource managers throughout this ecoregion. Climate change MQs can be grouped into several major categories:

1. **What are the projected impacts of climate change on resource availability**, such as aquatic or grazing resources?
2. **What is the projected influence of climate change on the ecological status of CEs?** For example, how will climate change affect the structure and function of ecological communities?
3. **What is the projected influence of climate change on distributions of species and ecological systems?** More specific questions in this category related to *What is the relative degree of potential risk for loss of particular communities, such as semi-desert grassland, or particular species, such as bats or sky island endemics?*
4. **What are the interactive effects of climate change together with other stressors, such as invasive species, on CEs and their ecological status?**
5. **What is the impact of climate change on restoration activities?** These questions seek to understand how current management activities might be modified in light of future projected changes, as well as which activities are likely to be most effective.

Of these general categories, the majority of MQs raised by resource managers fall into the second and third categories listed. The greatest number of questions focused on climate change impacts to community structure and function, followed closely by questions regarding the shifting distributions of plant and animal species or communities. Given the place-based nature of management decisions such as use authorizations, an understanding of how a given species' or community's geographic range might shift due to climate change is highly relevant to decision processes.

There is a clear emphasis on the need to understand the future conditions of aquatic resources under climate change. For these questions, a spatially explicit understanding of baseline conditions, recent trends, and multi-model climate projections for patterns of precipitation are required.

Managers are also understandably concerned with the potential effects of interacting stressors, particularly the combination of familiar agents such as invasive species or pathogen outbreaks, and the less familiar agent of climate change.

6.2 Water Availability and Altered Hydrology

Water availability is an on-going, driving issue permeating all aspects of life in this ecoregion. The primary anthropogenic (or cultural) water uses include irrigation for agricultural crops, municipal water supplies, industrial uses (primarily mining), and livestock. Agricultural, municipal and industrial consumptive water use within just the Arizona portion of the Madrean Archipelago ecoregion (shown in green outline in Figure 2-2) averages approximately 515,100 acre-feet per year (ADWR 2010a). In the Southeastern Arizona Planning Area (which roughly coincides with the Arizona portion of the ecoregional assessment area, except for excluding the greater Tucson area), the agricultural sector accounts for 85% of water used (ADWR 2010a). Municipal uses account for nearly 8% and industrial uses for nearly 7% of total cultural water used in the Southeastern Arizona Planning Area (ADWR 2010a)

In the Tucson Active Management Area (which falls almost entirely inside the ecoregional assessment area on its west side), annual water use averaged 341,600 acre-feet between 2001 and 2005 (ADWR 2010b). Municipal demand accounts for 53% of water use, while agriculture accounts for 32% and industry 15%.

Within Hidalgo County, southwestern New Mexico, a total of 102,434 acre-feet were used in 2005, with 92% obtained from groundwater sources (NMOSE 2008). Agriculture accounted for 93% of water used in the Hidalgo County portion of the ecoregion, while mining, the second largest use of water, accounted for nearly 4% of water used (NMOSE 2008).

Approximately 85% of the consumed water comes from groundwater in the Arizona portion of the MAR ecoregion and approximately 92% is from groundwater in the New Mexico portion. In the Tucson portion of the larger ecoregional assessment area – the Tucson Active Management Area – approximately 75% of the water used for all purposes comes from groundwater supplies (ADWR 2010b).

6.2.1 Anthropogenic Effects on Hydrologic Regime

Hydrology is shaped by land uses and human activities, as well as climate and topography. While dams can have enormous impacts on surface hydrology and the aquatic systems and species that depend upon them, their effect is limited within the MAR to the Gila River; the Gila River has the only major dam in the ecoregion. The San Pedro does not have a mainstem dam. In addition, as noted earlier, most cultural water usage is from groundwater supplies (or in the Tucson AMA, diversions from the Colorado River). Thus, this summary of human impacts on hydrology for this ecoregion focuses primarily on groundwater use and the relationship between groundwater and surface water interactions.

Groundwater recharge rates vary by basin, from approximately 5,000 to 15,000 acre-feet per year. Groundwater withdrawal rates for agricultural and municipal uses thus far exceed recharge rates in many basins in the ecoregion, creating a groundwater budget deficit (Tillman et al. 2011). These reductions have caused significant reductions in the groundwater discharges from the regional aquifers that formerly supported perennial baseflow at lower elevations, such as along the San Pedro River. Groundwater levels may become much lower around areas of high pumping, creating cones of depression in aquifer water levels. In some areas such cones of depression have changed the direction of groundwater flow, drawing water from, instead of discharging water to, formerly perennial stream reaches (Barlow and Leake 2012, Leake et al. 2008).

The significant entrenchment ("down-cutting") of stream channels since the late 1800s has greatly changed the timing and amounts of water soaking into alluvial aquifers during runoff events and may contribute to reduced alluvial aquifer discharge to support perennial baseflow (Hereford 1993, Noonan 2013, Webb and Leake 2006). This widespread stream incision is thought to have been initiated by several factors, partly stemming from natural climatic cycles and partly due to altered watershed conditions resulting from historical over-grazing in combination with regional drought (Noonan 2013, Stromberg and Tellman 2009, Webb et al. 2007); these substantial changes in channel geomorphology are irreversible. Groundwater pumping from the alluvial aquifers has also reduced their discharge to the lowland streams (Barlow and Leake 2012, Leake et al. 2008, Tillman et al. 2011). These changes have significantly altered groundwater/surface water interactions and hydrologic patterns along the alluvial stream valleys of the ecoregion, along both mainstem and tributary streams, as well as altering spring and seep hydrology (Barlow and Leake 2012, Leake et al. 2008, Tillman et al. 2011).

A study of 20th century (1913-2002) observed trends in precipitation and streamflow indicates that decreases in streamflows on the San Pedro River during this period are the result of factors other than precipitation change (Thomas and Pool 2006). Their study showed that significant increases in the areal extent in riparian vegetation along the river corridor and a change in upland vegetation from grassland to more woody cover – changes which are anthropogenically influenced – has increased the evapotransporation demand during summer and fall months, the same months with the greatest decrease in low flows. In addition, human activities, such as local, near-river seasonal groundwater pumping, also reduce summer-time low flows. The underlying causes of these trends in streamflow are supported by the lack of reduced flow in winter months (Thomas and Pool 2006).

6.2.2 Recent Effects of Climate Change on Hydrology

Historically, seasonal precipitation patterns have been reasonably consistent, with summer storms providing the bulk of the annual rainfall in "flashy" convective storms of short duration and higher volume, and winter storms providing about a third of the annual rainfall in wide-spread storms having lower volume and longer duration. These patterns appear to be changing. Although total annual rainfall for the San Pedro basin from 1900 to 2000 shows a constant long-term average, with no trend up or downwards (MacNish et al. 2009), the timing of peak discharges has shifted. The 1915-2005 flow record for the San Pedro River shows that annual flood peaks (which occur in the monsoon season, July-October) have declined, and the number of winter storms have increased in the latter half of the 20th century, such that winter storm flood-pulse magnitudes have exceeded summer flood magnitudes (Hirschboeck 2009). This shift has been observed in other rivers in the region. In the 1920s-1930s there were more convective (summer) storms, and the amount of winter precipitation (from cyclonic storms) has increased since 1965 (Hirschboeck 2009). As noted in the **Hydrology** section of the **Ecoregion Conceptual Model**, El Niño (warm phase of the Pacific Decadal Oscillation) and La Niña (cool phase) also play a role in the timing and type of storms that make their way into the Madrean Archipelago ecoregion. Generally, during warm El Niño phases, Arizona and New Mexico experience more wet years than dry compared to the long-term average (ADWR 2010a, 2010b, Stephens and Associates, Inc. 2005). In addition, the number of tropical storms (generally occurring in the fall) that reach the ecoregion also increased in the latter half of the 20th century (Hirschboeck 2009). The complexity of the sources of storms, their timing and amounts of precipitation may make future predictions of precipitation with global climate change even more difficult (Dixon et al. 2009, MacNish et al. 2009). This may also make it more difficult to forecast ecological consequence of global climate change. For example, a shift in the timing of storms to more winter and fall events may create more stable base flows and less dynamic summer floods. Aquatic ecosystems that evolved in the context of a more dynamic hydrologic regime could respond by shifting to greater amounts of narrower bands of mesquite or grasslands, as cottonwood and willow stands die off (Dixon et al. 2009) and could provide habitat for a different suite of aquatic fauna than occurs at present.

6.2.3 Altered Hydrology and CEs

In the context of the natural resources of this ecoregion, the overriding concern around cultural water use is the impact on aquatic ecosystems, and wildlife as a whole. Riparian and other aquatic ecosystems are crucial to the wildlife of the ecoregion: they provide water and "generally support the greatest concentrations of wildlife, providing the primary habitat, predator protection, breeding and nesting sites, shade, movement corridors, migration stopover sites, and food sources" (Levick et al. 2008). Krueper (1993) estimates that approximately 80% of all animal species in the desert Southwest rely on riparian habitat for at least part of their life histories. Loss of water from these systems has multiple impacts. Diversion of surface waters causes the loss of both base and runoff surface flows, and consequent loss of natural alluvial groundwater recharge/discharge dynamics (Poff et al. 2010, Shafroth et al. 2010, Theobald et al. 2010). Similarly, groundwater withdrawal reduces the quantity and spatial extent of baseflow of groundwater and lowers the alluvial water table (Calamusso 2005, Poff et al. 2010, Stromberg et al. 1996). As a result of these withdrawals, stream reaches may shift from perennial to intermittent flow, or intermittent to ephemeral; ciénegas and marshes may be reduced in extent or disappear entirely (e.g., San Simon Ciénega per Dinerstein et al. 2000), resulting in the decrease or localized loss of fish and other aquatic species associated with these systems (e.g., localized loss of fish species from the Santa Cruz River around Tucson (URS Corporation and CDM, Inc. 2002). Riparian vegetation is altered, reduced or lost as a consequence as well (Stromberg et al. 1996).

Ciénegas are of particular concern because they were once larger as well as far more abundant on active floodplains and in stream channels; they were typically found in low-relief, rolling grasslands or alluvial plains bounded by well-vegetated mountain fronts of the Madrean landscape (Hendrickson and Minckley 1984). The dense vegetation, low gradients, and deep surrounding upland soils slowed the rate and volume of runoff into these wetlands, contributing to their origin and perpetuation within a monsoon-driven hydrologic cycle (Hendrickson and Minckley 1984). They were greatly reduced in number and size due to severe arroyo downcutting from a complex interaction of drought and increased human and livestock use in the past century (Hendrickson and Minckley 1984). Historically, ciénegas were hydrologically stable because they were larger and able to buffer high flows (Stromberg and Tellman 2009). In addition, the surrounding uplands historically supported intact vegetation and deep soils that slowed and absorbed monsoon rains better than denuded and compacted soils. Monsoon rains that occurred after upland vegetation removal contributed to erosional forces that caused arroyo formation (see Figure 6-2) and may continue to contribute to further downcutting (Noonan 2013). Ciénegas on the outer edges of alluvial valley terraces and inactive floodplains are now isolated from stream flooding events due to the channel incision along the lowland streams that occupy these valleys. These now-isolated ciénegas remain fairly stable hydrologically as long as the groundwater sources of their springs remain unaltered.

Figure 6-2. Photos illustrating down-cutting of streams in the Madrean Archipelago.

Photo on the left is of the upper San Pedro, from Arizona State University’s Flora of the San Pedro Riparian National Conservation Area, Cochise County, Arizona; photo on the right is a tributary to the San Pedro, from Hastings 1959.

For more specifics on the effects of altered hydrology and water availability in relation to individual CEs, see the CE conceptual models associated with this report in **Appendices C** and **D**.

6.2.4 Management Concerns Around Water Availability and Hydrology

The concerns around the availability and use of water are reflected in the MQs that were identified in the Development Forums and other workshops. In all of the forums, water availability and hydrologic changes were among the top concerns expressed by participants. The hydrology-related questions that came out of the development forums or were identified in other REAs are characterized broadly by the example questions listed below. These concerns are fully expected, since the use of water in the desert to support human activities – irrigation farming, livestock watering, municipal and industrial development, and hydroelectric power generation and cooling of thermal power generation – usually deprives water-dependent species and ecosystems of this extremely limited resource.

The MQs suggested in the Development Forums that pertain to water availability and hydrology in the Madrean Archipelago ecoregion fall into the following broad groups:

1. **What is the current status of aquatic/wetland conservation elements?** For example, W*hat is the current distribution and condition of riparian/stream systems?*
2. **What are the current and projected future impacts of CAs on aquatic/wetland conservation elements**? For example, *Where do groundwater withdrawals affect ciénegas, and where will they potentially affect ciénegas in the future?*
3. **What was the historical condition of aquatic/wetland conservation elements?** For example, *What was the extent of perennial streams in the ecoregion prior to Anglo-American settlement (i.e., prior to mid/late-1800s)?* Such questions are important both for establishing reference conditions, against which to compare current conditions for conservation elements, and for placing the current conditions and management needs for conservation elements in their historical context.
4. **How have past human activities affected aquatic/wetland conservation elements?** For example, *How has past grazing affected the distribution and condition of perennial streams?*
5. **What is the current and projected future status of water resources in general?** This group of questions was generally not specific to any individual conservation element. For example, *What is the availability of water, both natural and man-made?*
6. **What is the legal status of water resources in general, and how may this affect water availability?** This group of questions similarly was not specific to any individual conservation element. For example, *What is the legal status of groundwater withdrawals that may affect streamflow, in Arizona and New Mexico?*
7. **What are the likely human responses to climate change and how may that further affect aquatic/wetland conservation elements?** For example, *How will human water uses – and their own associated impacts on conservation elements – change in response to climate change?*
8. **How should water resources and aquatic ecosystems be managed to sustain them?** A smaller number of questions related to how to manage and protect water resources and hydrologic regimes; for example, *How will watershed health, development, and groundwater resources be managed to protect aquatic habitat?*

6.3 Species of Management Concern: Invasive Non-Natives, Managed Non-Natives, and Native Woody "Increasers"

A number of species that are either not native to this ecoregion, or are native but expanding beyond their recent historical distribution, are of management concern. Whether native or not, invasive species can dramatically alter the species composition of native habitats and biotic assemblages through displacement, competition, or predation, and cause significant changes in ecosystem processes (e.g., invasive grass species that ignite easily may promote increased frequency and size of fires). For the purposes of this REA, these species are grouped into the following categories:

- **Invasive non-natives**: species that are both not native to this ecoregion **and** are invasive, thereby having negative impacts on native species and ecosystems; these species are typically managed in order to reduce, control, or eradicate them. Note that species introduced from elsewhere that are *not* having adverse impacts on native biodiversity are not of primary concern for the REA and consequently are not addressed here.
- **Managed non-natives**: species that are not native, but are intentionally managed to sustain the species; examples include game fish. Such species are desirable for recreation, but in some instances may have negative impacts on populations of native fish or other native species. As a result, in some areas these species may be intentionally managed for persistence while in others they may be targeted for eradication, depending on management goals for the area.
- **Native woody "increasers"**: For the purposes of this REA, the native mesquites (*Prosopis* spp.) and creosote bush (*Larrea tridentata*) that are expanding beyond their recent historical range are termed "native woody increasers." This phrase is used to describe species that are native to an area, but have been expanding their distribution beyond their recent historical range in response to altered disturbance

regimes and anthropogenic influences. (These native woody increasers may also have been very occasionally present on some parts of the landscape historically, but have greatly increased their density. The term “increaser” is borrowed and modified from its usage in range management, where it typically refers to species (usually grass species) that increase in dominance in response to increased levels of grazing.) These species are native to this ecoregion and their distribution and prevalence on the landscape has shifted back and forth in response to natural climate patterns and anthropogenic influences (Van Devender 1995). Because these species have naturally varied in their distribution over longer historical time frames, there is concern around characterizing them as “invasive;” the terms used to describe this group of species are acknowledged to be imperfect.

Non-native species are introduced into a region from somewhere else, either intentionally or accidentally. Most non-native plants are relatively innocuous additions to local floras, with a relatively small proportion of introduced species becoming invasive and threatening native species and ecosystems. The most serious impact of the introduction of an invasive non-native species is the conversion of one biotic community to another – e.g., conversion of a grassland to a shrubland. Also problematic is the extensive displacement or reduction in abundance of native species – e.g., native grasslands becoming dominated by Lehmann’s lovegrass (*Eragrostis lehmanniana*).

The remainder of this section lists and characterizes invasive or non-native species that were identified either in REA workshops or through literature review and were indicated to be of significant concern in this ecoregion. These characterizations are organized by the three categories of species of management concern (invasive non-natives, managed non-natives, and native woody increasers), and within the invasive non-natives category, by broad ecosystem types. Other species of potential concern for this ecoregion are summarized in **Appendix F**. For more specifics on the effects of various invasive or non-native or native woody increaser species in relation to individual CEs, see the CE conceptual models associated with this report (**Appendices C, D,** and **E**).

6.3.1 Invasive Non-Natives

Riparian and Aquatic Invaders

The most modified and invaded habitats in the MAR are riparian and aquatic habitats. Demands for water for agriculture, livestock grazing, and urban uses have increased dramatically in the last 130 years (Bahre 1991). As described above, groundwater pumping, stock tanks, reservoirs and flood control features have altered local hydrology and watersheds. Water, nutrients and seeds harvested from the entire watershed are concentrated in drainages that often experience high-energy floods with sediment erosion and deposition. This makes riparian habitats the most unstable ecosystems in this region, providing ideal conditions for the establishment and spread of invasive species. Non-native plants are usually diverse and abundant in riparian habitats.

Salt cedar (*Tamarix chinensis*) is an aggressive invader of riverine habitats from central Arizona north into Utah and western Colorado. It often nearly completely replaces native species with dense thickets and is an aggressive water consumer. However, tamarisk-dominated riparian vegetation does provide habitat for species such as the endangered southwestern willow flycatcher (*Empidonax traillii extimus*). Some studies anticipate that tamarisk may expand its geographic distribution as a result of global climate change (e.g., Bradley et al. 2009), including southward along the San Pedro; however, tamarisk has also been documented to decline along the San Pedro River where perennial flows have been re-established (Stromberg et al. 2009). Since 2001, the introduction of a biologic control agent, the Mediterranean tamarisk beetle (*Diorhabda elongata*), has locally reduced tamarisk populations by 75-85% over 2-3 year period in some areas (DeLoach et al. 2000, DeLoach and Carruthers 2004, Lewis et al. 2003). The beetle’s spread has been aided by unintentional human activities, rapidly expanding populations beyond what was originally planned, and they are expected to spread widely across the western United States (Sogge et al. 2008). The beetle, originally restricted to latitudes north of 37.1° by day length-induced reproductive diapause, has been documented to adapt, allowing for its expansion at the southernmost extent of its range (Dudley and Bean 2012). While the likelihood of the spread of the tamarisk beetle in the MAR ecoregion is not entirely clear, organizations and agencies working to protect riparian habitat and associated species anticipate the beetle will move into the region over the next three years and have begun active restoration efforts in preparation (e.g., Gila Watershed Partnership, Bureau of Land Management, and Desert Landscape Conservation Cooperative). Although tamarisk is an invasive non-native that has greatly altered riparian vegetation, in the absence of suitable native vegetation, there are concerns that rapid loss following the introduction of the beetle would have negative impacts on wildlife currently dependent on tamarisk-dominated vegetation; it is unknown how quickly other, native riparian species might replace dead expanses of tamarisk.

Non-native crayfish, fishes such as mosquito fish (*Gambusia affinis*) and red shiner (*Notropis lutrensis*), American bullfrog (*Lithobates catesbeiana*), and barred tiger salamander (*Ambystoma tigrinum* subsp. *mavortium*) have altered aquatic ecosystems. The American bullfrog is an extreme invader in MAR aquatic habitats, and often extirpates native species. Northern crayfish (*Orconectes virilis*) is also a serious competitor and predator that has no natural predators, consumes larval fish, plants, and insects, and can severely harm ecosystems. It is established in aquatic habitats in the Huachuca Mountains, Rose Canyon Lake in the Santa Catalina Mountains, and the San Pedro River.

Feral swine (*Sus scrofa*) are present in the eastern portion of New Mexico, near Redington and Wilcox in Arizona and impact wetland habitats by rooting and wallowing. They are difficult to control and affect native species by competing with or consuming them, as well as spreading disease.

Invasive Grasses and Forbs

Although terrestrial habitats are more stable than riparian habitats, they have also been invaded with a variety of invasive non-native species. Semi-desert grassland is highly impacted by livestock grazing and infrastructure modifications related to it (roads, fences, stock tanks, etc.). Roadsides are dispersal corridors for non-native grasses and other species. These land uses and infrastructure features have facilitated the introduction and continuing spread of invasive species into these ecosystems. In response to erosion and demand for cattle forage, species such as Lehmann's lovegrass (*Eragrostis lehmanniana*) were widely introduced into grasslands in southeastern Arizona and adjacent Sonora, Mexico, often at the expense of native bunch grasses. As a result, the spread of non-native perennial grasses within grasslands in this ecoregion has been substantial. As documented by Gori et al. (2012), Lehmann's lovegrass and, to a lesser extent, Boer lovegrass (*Eragrostis curvula*) are common on at least 1.5 million acres (607,000 ha) in this ecoregion; non-native grasslands with little to moderate woody increase now comprise 11% of the area's current and former grasslands. Other non-native grasses common in semi-desert grassland include fountaingrass (*Pennisetum setaceum*) and Natalgrass (*Melinis repens* ssp. *repens*), which have spread more slowly (Van Devender et al. 2007). Native grasses are still present in many invaded areas, but at a lower density. In many areas, non-native spring annuals, including arugula (*Eruca vesicaria* ssp. *sativa*), Malta star-thistle (*Centaurea melitensis*), red brome (*Bromus rubens*), Sahara mustard (*Brassica tournefortii*), and various less invasive species (hoary bowlesia (*Bowlesia incana),* redstem stork's bill *(Erodium cicutarium),* London rocket (*Sisymbrium irio*)*,* etc.), as well as Bermuda grass (*Cynodon dactylon*) and tick grass (*Eragrostis echinochloidea*) are present and common. Brief characterizations of invasive species of substantial concern in semi-desert grasslands are provided below.

Buffelgrass (*Pennisetum ciliare*) is a stout, shrub-like grass native to the warm parts of Africa, India, and Madagascar. It is a serious invader in Arizona and Sonora, Mexico. It was introduced very successfully in Sonora for cattle forage in the 1950s. It is intensively planted in central Sonora, and in foothills thornscrub and tropical deciduous forest in east-central Sonora, but not in the MAR in northeastern Sonora. It invades natural habitats in Sonoran desertscrub at around 1800-2800 ft (550-830 m) elevation in Arizona. In Sonora, it is invasive at increasingly lower elevations where relative humidity increases toward the Gulf of California.

In the MAR, it has extended its distribution into semi-desert grassland along roadsides in the Douglas and Agua Prieta areas, as well as the greater Tucson area (see mapping by the Arizona Sonora Desert Museum: http://www.desertmuseum.org/programs/images/NPCI_Buffel_alldata_1500V.jpg). Buffelgrass continues to expand rapidly, with patches in southern Arizona documented to have doubled in size every 2-7 years since 1988 (Hunter 2011). There are rumors of planting of the cold-tolerant "Frio" variety in the Cananea area in Sonora, Mexico, but there is no documentation of this action being implemented. Buffelgrass is a very aggressive competitor for water and space, effectively eliminating most native annuals and short-lived perennials when it becomes established. Native plant richness and diversity has declined in invaded areas in southern Arizona with increasing time since invasion (Olsson et al. 2011). With warmer climates it will likely expand eastward and upward in elevation into semi-desert grassland in the MAR.

Buffelgrass displaces native species both through direct competition and by altering fire regimes in areas where it is present. Buffelgrass has a large root base and regrows from each node on the stems, not just the basal root crown. The foliage has high lignin content and burns intensely. Fire is rare in desertscrub and thornscrub; it is not a driving ecological process in these biotic communities, and therefore most native species in these communities are highly vulnerable to fire. In the arid southwest, buffelgrass' characteristics promote the spread of fire and it re-sprouts readily after fire, excluding native vegetation and thereby altering plant communities. There is evidence that buffelgrass-fueled fire has initiated a positive fire-invasion feedback. In places, Sonoran desertscrub has been converted to a savanna-like grassland (McDonald and McPherson 2011). Over 2.4 million acres (1 million ha) in central Sonora, Mexico, have been converted from native desert scrub and thorn scrub to *P. ciliare* pasture since the 1940s (Van Devender et al. 1997).

Lehmann's lovegrass (*Eragrostis lehmanniana*) is a bunch grass native to South Africa. It was first introduced in the arid Southwest in the 1930s for range restoration purposes. Between 1940 and 1980, ranchers and government land managers established Lehmann's lovegrass on more than 172,000 acres (70,000 ha, Cox et al. 1988). However, because of edaphic and climatic requirements of the plant, most stands in Texas, New Mexico, and central Arizona disappeared within 5 years of planting (Cox et al. 1986). In 1988, Lehmann's lovegrass was considered a major plant species on about 347,000 acres (140,000 ha), with the majority of this acreage in southeastern Arizona (Cox et al. 1988). Lehmann's lovegrass has persisted since its introduction in 1932 and spread primarily in desertscrub and semi-desert grassland ecosystems of southeastern Arizona at elevations between 3,250 and 4,800 feet (1,000 and 1,460 m); it can spread aggressively and displace native grasses. Anable et al. (1992) estimate at least 358,300 acres (145,000 ha) of semi-desert grassland in Arizona are heavily invaded by Lehmann's lovegrass. The plant grows best on sites with sandy- to sandy loam-textured soils, and where winter temperatures rarely drop below 32 degrees Fahrenheit (0 degrees Celsius) and summer rainfall ranges between 6 and 8.6 inches (150 and 220 mm; Cox et al. 1987, 1988, Thornburg 1982).

The palatability of Lehmann's lovegrass for cattle is low during the summer and it is generally lightly grazed at that time. Cattle make greater use of this grass during fall, winter, and spring because the foliage remains green longer than most native grasses (Cable 1971, Cox et al. 1988, Humphrey 1970, Mooney et al.1981).

Weeping lovegrass (*Eragrostis curvula*) is a rapidly growing warm-season bunchgrass native from South Africa north to Rhodesia [Zimbabwe] and Transvaal in east Africa (Duke 1983, Ruyle and Young 1997).

Boer lovegrass (*E. c.* var. *conferta*) is a variant recognized by some; however, Flora of North America (Barkworth et al. 2003) does not recognize varieties in *E. curvula.* It was brought to the United States from Tanganyika in 1932 (Alderson and Sharp 1993, Crider 1945 in Cox et al. 1988). Presently it occurs in the southern half of the United States as well as Oregon and Washington (USDA Plants Profile 2013).

Eragrostis curvula is common in southeastern Arizona north to the Mogollon Rim and northwestern Arizona. It is only known in Sonora, Mexico from a few localities in the Animas Valley and Sierra San Luis very close to the Arizona border. From Flagstaff southward, Boer lovegrass occurs in the same areas. During the 1940s to 1950s, *Eragrostis curvula* was seeded on the upland mesas on the Appleton-Whittell Research Sanctuary in Santa Cruz County, Arizona (Walsh 1994). In 1951, *E. curvula* was aerially seeded after fire in the Pinal Mountain area in Arizona (Pond and Cable 1962 in Walsh 1994). It has also been seeded extensively for erosion control along banks and slopes of highways and mine spoils, on revegetated sites (Dalrymple 1970a, Soil Conservation Service 1972), and in range and pasture sites (Alderson and Sharp 1993).

Native plant canopy, plant species richness, shrub density, and shrub canopy were significantly reduced on plots with *Eragrostis curvula* in semi-desert grassland in Santa Cruz County, Arizona (Walsh 1994). Boer lovegrass has successfully established in native mixed-grass species grasslands in the southwestern United States, resulting in changes in desert grassland flora and fauna (Parmenter and Van Devender 1995). *Eragrostis curvula* produces more fine fuels than native species (Cox et al. 1984 in McPherson 1995), and generally increases (Wright et al. 1978 in Walsh 1994) or remains in stable numbers after fire (Walsh 1994).

Eragrostis curvula is adapted to semi-arid and desert environments (Duke 1983) at elevations mostly below 5,000 ft (1,524 m) elevation having summer rainfall (Dahl and Cotter 1984, Dittberner and Olson 1983) and at least 16 in. (432 mm) mean annual precipitation (Ruyle and Young 1997, Soil Conservation Service 1972). Prolonged drought can kill well-established *Eragrostis curvula* stands (Dahl and Cotter 1984 in Walsh 1994). *Eragrostis curvula* is semi-hardy, moderately frost-resistant in southern areas, but likely killed during extended periods having temperatures below 10°F (-12.2°C) (Duke 1983, Ruyle and Young 1997). *Eragrostis curvula* var. *conferta* is drought resistant, but less cold tolerant (Alderson and Sharp 1993), limited to areas where temperatures do not drop below 0°F (-17.8°C). It grows best where annual precipitation is 13 in (330 mm) or more (Ruyle and Young 1997).

With increased warming in the future, both varieties of *E. curvula* are likely to move to higher elevations in semi-desert grassland, and would likely increase with greater summer precipitation.

Red brome (*Bromus rubens*) is a weedy annual now common throughout southwest U.S. that poses a similar threat of promoting fire in ecosystems not adapted to fire. It is a serious invasive in Sonoran desertscrub and out-competes native grasses, grows prolifically with winter rainfall, and is dispersed by seeds spreading to disturbed areas along roadways, rangelands, and agricultural lands.

Fountaingrass (*Pennisetum setaceum*) is a large perennial ornamental grass that has been cultivated in Tucson since the late 1940s (Van Devender et al. 2007). It readily escapes from gardens and urban roadcuts into natural habitats in the southwestern United States, especially in Sonoran desertscrub and semi-desert grassland in the Phoenix and Tucson areas in Arizona. Fountaingrass was first collected in the Santa Catalina Mountains in 1946. It is actively spreading along Interstate 19 from Tucson south into Santa Cruz County. It has been recorded up to 5,750 ft (1,753 m) in the Catalinas and 7,140 ft (2,175 m) elevation in Santa Rita Mountains. It will very likely expand in the MAR with warmer temperatures.

Natalgrass (*Melinis repens* ssp. *repens*) is common on roadsides at moderate elevations in central MAR from Tucson south. It is a locally serious invasive and fire hazard in semi-desert grassland in the Mule Mountains west of Bisbee. In many areas in northeastern Sonora southward into central Mexico, it is a very serious invasive, displacing natives and promoting the spread of fire. With warming, Natalgrass is very likely to become more invasive in the MAR and more of a fire hazard.

Sweet resinbush (*Euryops multifidus*) is a shrub that was introduced on Frye Mesa near Thatcher, and has proved to be a strong competitor in semi-desert grassland.

Soft feather pappusgrass (*Enneapogon cenchroides*) is a perennial grass native to Africa, India, and the Arabian Peninsula. In the United States, it only occurs in Pima County, Arizona. It was first collected in the Santa Catalina Mountains in 1976, and has steadily increased in semi-desert grassland in the range. Subsequently, it was recorded from the Galiuro, Santa Rita, and Tucson Mountains, and Organ Pipe Cactus National Monument. This species is likely to expand with warmer climates.

Feathertop grass (*Pennisetum villosum*) is a very attractive cultivated grass. In the Sierra Madre Occidental in Durango, it is an extremely serious invasive in grassland and montane forest openings. It escaped from gardens in Bisbee as early as 1983. It is a potentially severe invasive in the MAR mountain ranges.

Invaders in Woodlands and Forests

With warming, the semi-desert grassland-oak woodland ecotone is expected to shift upward. Pine forests similar to those on the Mogollon Rim and in the Graham and Santa Catalina Mountains are not well developed in sky island ranges close to the border, in northeastern Sonora, or in the Sierra Madre Occidental, where oaks are typical co-dominants in pine-oak forest. Oaks may increase in these high elevation forests in the northern part of the MAR in the future. Under this context, the only potential invasive threat to the MAR woodlands and forest would be a northward expansion of the Madrean bark beetle (*Dendroctonus rhizophagus*); however, the beetle may not be able to survive in warmer summer temperatures given what is currently known about its temperature preferences (see discussion for this species in **Appendix F**).

6.3.2 Managed Non-native Species

Managed non-native fish species include green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), and brown trout (*Salmo trutta*); along with other bass, a variety of trout, and catfish, these species have been widely introduced in MAR lakes, reservoirs, and streams (USFWS 2007) and are managed for sport fishing. As noted earlier in this section, such species are desirable for recreation, but in some instances may have negative impacts on populations of native fish or other native species. The impacts of some of the sport fishes on aquatic systems in general, and specifically the threatened Chiricahua leopard frog (*Lithobates chiricahuensis*), are discussed in USFWS (2007). For example, the green sunfish is highly adaptable, tolerant of crowding, and may both consume or compete with native fish species for prey, as well as consume a wide variety of other aquatic fauna (Minckley 1973). As a result, these species may be intentionally managed for persistence in certain designated areas, while in others they may be targeted for control or eradication, depending on whether they are impacting the ability to meet management goals for the area. Native Apache trout (*Oncorhynchus apache*) populations have experienced massive range reductions in the region due to habitat alteration and competition with brown and brook trouts (Rhine 1996). Native fish species are primarily generalists, consuming insects and algae, while non-native fish are primarily piscivores. Non-native fishes have also evolved behavioral traits that allow them to persist within intensely competitive fish communities. One result of this is that native fishes fail to recruit in the presence of non-native competitors (BOR 2009).

6.3.3 Native Woody Increasers: Mesquite and Other Shrub Expansion

Over millennial time frames, semi-desert grasslands of this region have displayed two climate-driven phases, with grass dominance in periods with strong summer precipitation and shrub dominance in periods with more summer drought (Burgess 1995, Van Devender 1995). Native shrubs such as mesquite (*Prosopis glandulosa* var. *torreyana* and *P. velutina*[3]) and creosote bush (*Larrea tridentata*) have invaded semi-desert grasslands of this region three times in the last 4,000 years (Van Devender 1995). The first two cycles of shrub expansion were driven by long-term drought. The most recent period of shrub increase began in the 1880s and has resulted in the conversion of extensive areas of semi-desert grassland, especially those formerly dominated by black grama (*Bouteloua eriopoda*), in Trans-Pecos Texas, southern New Mexico and southeastern Arizona (Hennessy et al. 1983, York and Dick-Peddie 1969), to mesquite upland scrub. Gori and Enquist (2003) estimate that 84% of the historical (pre-1880s) extent of semi-desert grasslands have some degree of shrub invasion, and 37% has been completely converted to a shrub-dominanted system. The mesquite upland scrub type is currently estimated to occupy approximately 20% of the ecoregion, based on vegetation mapping by NatureServe (2013). To provide some indication of the degree of creosote bush encroachment, Humphrey and Mehrhoff (1958) documented a 73-fold increase in the acreage it occupied at the Santa Rita Experimental Range (south of Tucson) over a 50-year period from around 1900 to the 1950s; just east of the MAR on the Jornada Range, mesquite (*Prosopis* spp.), tarbush (*Flourensia cernua*) and creosote bush occupied approximately 42% of the Jornada Range in the 1850s; by the early 1960s, these shrub species were found through the entirety of the Range (Buffington and Herbel 1965).

In light of on-going mesquite expansion, resource managers are concerned about the potential to retain and restore current semi-desert grasslands for biodiversity considerations. Understanding the role of livestock grazing and other anthropogenic drivers in conjunction with the projected increase in drought frequency and intensity for this ecoregion is critical for understanding restoration potential, given the expected shift (on decadal and longer time frames) toward shrub dominance during dry periods.

6.3.4 Management Concerns Around Invasive Non-Native Species and Native Woody Increasers

Resource managers also identified a number of information needs relating to species that are undesirable from a biodiversity management perspective. In addition to understanding the current and potential distribution of these species, there is also a need to understand how other CAs (e.g., climate change, etc.) may influence the spread and future distribution of these species.

1. **Which invasive non-native species are of greatest concern in relation to managing native ecosystems and species and maintaining their ecological status?**
2. **What is the current distribution of invasive non-native species and other species that are undesirable from a biodiversity management perspective?**
3. **Where are invasive non-native species projected to expand their geographic distribution?**
4. **Which problematic non-native species not currently present in this ecoregion are likely to be introduced and become established?**
5. **How will climate change and anthropogenic activities influence the expansion of existing invasive non-native species and the introduction of invasive species not currently present in the ecoregion?**

[3] Considering a radiocarbon date of 11,740 yr B.P. on velvet mesquite fruits from a packrat midden in the Waterman Mountains west of Tucson (Anderson and Van Devender 1991), *Prosopis velutina* is clearly native.

6. **How will the geographic distribution and dominance of native woody increasers (mesquites, creosote bush) change in response to climate change?** This can help inform the likely effectiveness and feasibility of restoration of mesquite-dominated shrublands to semi-desert grassland.

6.4 Fire

Fire regimes of the Madrean have changed dramatically since European settlement. The major drivers of this change have been the introduction of domestic livestock, fire suppression, and the invasion of non-native grasses including buffelgrass (*Pennisetum ciliare*) and Lehmann's lovegrass (*Eragrostis lehmanniana*) (McPherson and Weltzin 2000). Each of these has individually contributed to changes in different ecosystem components and their interaction has resulted in region-wide changes in vegetation structure and composition.

While cattle were introduced to this region at the beginning of the 17th century, they didn't become common until the middle of the 19th century. After 1850, the great expanse of semi-desert grasslands was increasingly more heavily stocked with cattle. As a result of their abundance, these animals effectively removed the grasses that created the fine fuels that historically carried the frequent fires throughout the landscape. This, in turn, promoted the expansion of woody shrubs into historical grasslands (Bahre and Hutchinson 2001) and allowed for the accumulation of woody fuels within these areas. Finally, cattle facilitate the invasion of invasive non-native grasses, which can further alter fire regimes (McPherson and Weltzin 2000). (Livestock grazing effects are discussed in more detail in the subsequent section, **Grazing**, in this chapter.)

Invasive non-native grasses, notably Lehmann's lovegrass (*Eragrostis lehmanniana*) and buffelgrass (*Pennisetum ciliare*), contain more lignin than the native grasses and decompose more slowly as a result, as noted in previous sections of this report. Therefore, they maintain a greater fine fuel load than the native grasses, thus changing the intensity of fires where these species are dominant; this results in the loss of native grassland and woodland forbs not adapted to this new fire regime (McPherson and Weltzin 2000). These exotic grasses are also able to invade communities that historically never accumulated sufficient fuels to carry a fire. Once invaded, these communities can transition into exotic grasslands following a single fire event.

Fire suppression starting in the middle of the 20th century resulted in further accumulation of fuels in the region's forests. As a result of on-going fire suppression, exacerbated by climate change, these forests now experience mixed-intensity or stand-replacing fires rather than the historical low-intensity fires. From 2002-2011, three of the worst wildfires in Arizona history occurred: in 2002 the Rodeo-Chediski fire burned 500,000 acres (202,300 ha); the 2005 Cave Creek Complex fire burned 250,000 acres (101,000 ha); and in 2011 the Horseshoe-2 fire burned 222,954 acres (90,226 ha; Heinz Center 2011b). These fires took place during the same nine-year period in which two of the driest years in a century and two of the lowest levels of run-off ever were recorded (AZ CCAG 2006). High-intensity wildfire can have catastrophic effects including erosion, loss of seed sources for natural regeneration of tree species, wildlife habitat loss, a breakdown in the proper functioning of ecosystems, and reduced future site productivity. While the implications for catastrophic wildfire are obvious, such conditions are also favorable for insect and disease epidemics. Insects are often attracted to drought-stressed, fire-damaged or killed trees and their build-up in these weakened hosts can threaten adjacent, unburned stands.

For more specifics on the effects of altered fire regimes in relation to individual CEs, see the CE conceptual models associated with this report (**Appendices C** and **D**).

6.4.1 Management Concerns Around Fire

As a driving ecological process for many ecosystems in the Madrean Archipelago, resource managers identified a number of specific information needs relating to fire in the course of the development forums and other workshops. Compared to questions around water availability and hydrology, climate change, and other CAs, the proportion of all questions relating to fire was somewhat smaller.

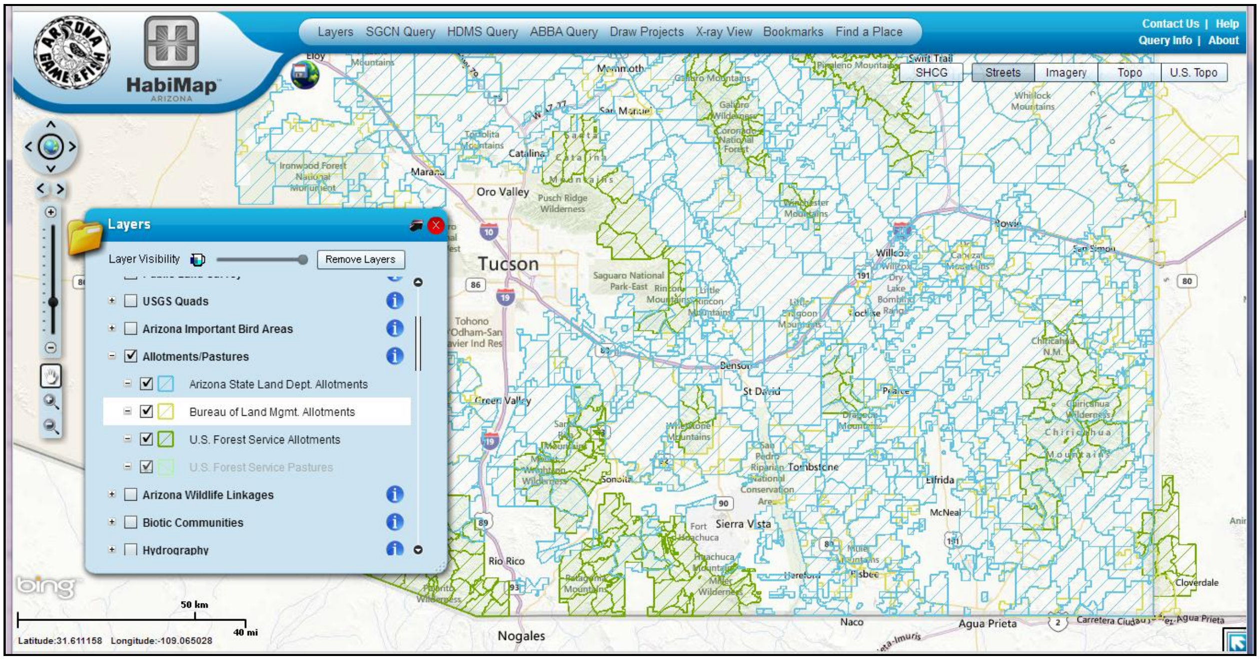
1. **What is the ecological status of CEs in relation to fire?** For example, *Where are the ecosystems that are and are not within acceptable range of variation and where could they be restored to an acceptable regime?* A related question is, *What is the degree and pattern of ecological departure for fire-adapted ecosystems within the Madrean?*
2. **What are acceptable ranges of variation for fire regimes in fire-adapted ecosystems?** This was also phrased as *How should fire regimes in the MAR ecoregion be characterized in terms of acceptable (not historical) range of variation relative to current ecosystems?*
3. **Which watersheds with sensitive soils and riparian resources are at risk from increased fire**, particularly high-intensity fires? Fuels build up under full fire suppression, resulting in higher risk of more severe fires, which can greatly alter post-fire patterns of surface runoff in watersheds and result in significant ecosystem alterations.
4. **How do fire regimes affect species CEs?** For example, *How do fires affect fish populations (Gila chub, Gila top minnow)?*
5. **What other CAs are affecting fire regime, how are they affecting it, and what is their distribution?** For example, *How do invasive grass species such as buffelgrass and cheatgrass affect native fire regimes, intensity, seasonality, and native plant mortality?* Or, *How will increased ignition sources (human), coupled with precipitation extremes (i.e., none to unseasonal precipitation) affect fire regimes?*
6. **Which factors may limit the use of fire as a management tool and where are these limiting factors present?** Potential limiting factors include presence or spread of pyrogenic invasive species, woody invasion of grasslands, and fire management limitations due to wildland-urban interface.

6.5 Development and Other Land Uses

6.5.1 Grazing

Livestock grazing is the most widespread land use in this ecoregion (based on the Arizona HabiMap compilation of BLM, USFS, and Arizona State Lands grazing allotment extents, Figure 6-3, and Community by Design 2011). Livestock use in the west affects a much greater proportion of BLM and USFS lands than roads, timber harvest, and fire combined (Beschta et al. 2012). Much of the land base is publicly owned (see Table 5-1), and both federal (BLM and USFS) and state agencies lease grazing allotments (U.S. Government Accountability Office 2005). Grazing occurs across the landscape, at all elevations and in all ecosystems (Beschta et al. 2012). Domestic livestock grazing is an extensive land use on Coronado National Forest grasslands, with moderate levels in the Madrean forests and limited levels occurring in desert communities (Coronado National Forest 2009). Grazing management practices, including stocking rates, may vary substantially and frequently in response to both environmental and market conditions (R. Mondt, pers. comm. 2013). A typical ranching operation on USFS land is centered around a small parcel of privately owned land, with grazing occurring on adjacent leased allotments totaling up to tens of thousands of acres. Stock tanks to supply water may be spring-fed or spring-supplemented, fed by runoff captured from arroyos, or pumped from groundwater using windmills, diesel, or more recently, solar-powered pumps (R. Mondt, pers. comm. 2013). Cattle are the predominant livestock in the ecoregion.

Figure 6-3. Map showing Arizona Game and Fish Department's compilation of grazing allotments for BLM, USFS, and state lands from its HabiMap Arizona on-line data viewer. The map is zoomed in on southeastern Arizona, around the Madrean Archipelago ecoregion (See http://habimap.org/habimap/.)



In the late 1800s, livestock grazing became a major land use in this ecoregion (and the desert southwest in general) as a result of a confluence of factors. The following summary of historical grazing and accompanying climate patterns is developed from Milchunas (2006) unless otherwise noted. From around 1880 to the passage in 1934 of the Taylor Grazing Act, grazing took place in this ecoregion (and beyond) at a level of intensity that is widely considered to be over-grazing, resulting in loss of vegetative cover and soil erosion. During this period, fire regimes were also being altered by fire suppression associated with settlement and loss of fuels from grazing. As summarized by various authors (e.g., Sayre 2005, Weltzin et al. 1997), it is likely that historical grazing practices, in conjunction with fire suppression and other anthropogenic activities and influences, was one of the key factors contributing to the expansion of mesquite (*Prosopis* spp.) in semi-desert grasslands. Similarly, the interacting effects of over-grazing, woodcutting, and other activities may have contributed to the extreme down-cutting and arroyo formation in floodplains in the region. However, there were two periods of intense drought (1880s and 1920s), with a year of extreme rainfall in 1905 during the period of extreme over-grazing. In addition, several decades after the 1934 regulation of grazing, there was a period of increased winter precipitation between 1975 and 1995 as well as another significant period of drought in the 1950s. These climatic patterns and events likely also contributed to these ecosystem impacts, and the possibility that these ecosystem changes would have occurred in the absence of these anthropogenic activities cannot be ruled out.

Impacts from present-day livestock grazing are variable, and often synergistic with factors including climate patterns (droughts, precipitation quantity and timing), past grazing history, fire, and other herbivores (e.g., prairie dogs), but intensive grazing generally degrades or alters the ecosystems in this region. Milchunas (2006) reviewed the literature to summarize the effects of current cattle grazing on 25 plant communities in the southwestern United States; the subsequent summary of present-day grazing impacts is drawn from that literature review unless otherwise noted. Potential effects from grazing include shifts in species composition, shifts in vegetation physiognomy (i.e., changing from grass-dominated to shrub-dominated), changes in plant productivity, and changes in soil compaction and nutrient levels.

In the semi-desert grasslands (termed “mesquite savanna” in Milchunas 2006) characteristic of this ecoregion, the studies reviewed indicate that grazing effects are variable and are dependent not only on grazing intensity, but also recent climate (periods of drought or above-average precipitation), local site characteristics (soils), past grazing history, and other factors shaping initial conditions at the research sites. Where grazing intensity was specified, more intense grazing was generally shown to alter species composition (e.g., reducing the cover of dominant, late-seral grasses) and decreasing productivity. A number of studies where grazing intensity was not specifically characterized showed no differences or no consistent trends in the differences in species composition between grazed and ungrazed areas. In others, the effects of moderate or light grazing on species composition are variable, and sometimes have the same effect as no grazing. Many of the studies indicate that the grazing history of a particular site, its soil characteristics, and recent climate patterns are key factors that will influence its response to present-day grazing. With regard to mesquite (*Prosopis* spp.) expansion in these grasslands, the research summarized in this review generally indicates that mesquite expansion occurs regardless of whether grazing is present; however, it is critical to keep in mind that grazing may still influence shrub expansion through interactions with fire or with past grazing history.

Studies quantifying the direct effects of grazing on plant composition in Madrean woodlands were unavailable. However, Milchunas (2006) notes that the grassland component of this woodland system may not be tolerant of heavy grazing due to the shift from perennial to annual grasses under heavier grazing and the associated potential for large areas of bare ground to develop and erode away, a series of effects that have been qualitatively described for this woodland. In addition, other research indicates that the decreased fine fuel loads caused by grazing, in conjunction with fire suppression in lower elevations, likely lengthened the fire return interval in these woodlands since the late 1800s (when grazing became a significant land use in this region). However, as fire suppression continued, it has led to an increase in the density of woody species (e.g., Barton 1999, Gori and Enquist 2003, Muldavin et al. 2002, Turner et al. 2003); although the frequency of fire may be reduced through fire suppression, the resulting higher woody fuel loads increased severity of fire in conifer-oak forests and woodlands and adjacent vegetation types like encinal across much of the southwestern US and adjacent Mexico (Kaib et al. 1996, Swetnam and Baisan 1996). Consequently, potential effects of present-day grazing on fine fuels and fire patterns in these woodlands are outweighed by the effects of modern fire suppression and its interactions with other variables (McPherson and Weltzin 2000); see the previous section on **Fire** in this chapter.

Riparian and wetland systems can experience negative impacts from livestock grazing as well. Trampling and soil compaction may contribute to lack of reproduction or recruitment of woody species (in riparian systems, e.g., cottonwoods), and subsequent erosion and changes in channel morphology, decrease in vegetative cover, changes in species composition and vegetation structure, and altered hydrologic regime (e.g., increase in flash flooding). As with upland ecosystems, grazing may interact with other variables such as lowered water tables, fire in the watershed resulting in significant loss of vegetative cover, and invasive species to have negative effects on these wetland systems. In addition, other site-specific characteristics such as geomorphology and hydrology may influence the degree or type of effect from grazing. However, on some sites, grazing may have no effect, and other variables are contributing to decreased recruitment of riparian vegetation (e.g., one study showed that Fremont cottonwood (*Populus fremontii*) recruitment was not influenced by grazing).

The range and variability of grazing’s effects on habitats results in similarly variable effects on the species utilizing these habitats. For example, in grasslands in this ecoregion, grazing has been documented to benefit certain grassland birds, while negatively affecting rodent populations (Bock et al. 1984). Research conducted in riparian systems in this ecoregion indicated that the removal of grazing substantially benefited breeding birds in general, and particularly riparian species (Krueper et al. 2003). Barbed wire fencing used to contain livestock can impede the movement of large mammals such as pronghorn (*Antilocarpa americana*). For more specifics on how livestock grazing may affect individual CEs, see the CE conceptual models associated with this report (**Appendices C** and **D**).

6.5.2 Municipalities, Utilities, and Related Infrastructure

Population and Development

As described in the **Human Context** section, within the ecoregion, the human population is concentrated in relatively small municipalities along the Interstate 10 and Interstate 19 corridors or low-lying areas in other parts of the ecoregion. Of the communities with populations over 10,000, Sierra Vista has had the largest growth rate. In the Arizona portion of the ecoregion, outside of the Tucson metropolitan area, the population is projected to increase by approximately 56% by 2030 (ADWR 2010a). In the New Mexico portion, the population has decreased by approximately 18% since the 2000 census.

In the larger ecoregional assessment area, Pima County as a whole grew by over 700% between 1950 and 2012, reaching a population of nearly one million, and the greater Tucson metropolitan area has experienced one of the highest growth rates in the nation over the last twenty years. The Tucson metropolitan area represents the primary location for continued significant suburban expansion in this otherwise sparsely populated assessment area; by 2040, the population of Pima County as a whole is projected to reach nearly 1.45 million (Pima Association of Governments 2013).

Population growth in this ecoregion is expected to follow past patterns of continued expansion of suburban and exurban development, and potentially rural residential development, especially around Tucson and in Pima County. Subdivision of ranches has been taking place in valley bottoms (Marshall et al. 2004), as well as upland grasslands (e.g., in the Sonoita Valley, J. Ruth, pers. comm. 2013); this could eventually result in areas of low-density, rural residential development in previously contiguous habitat.

The footprint of urban areas or other municipalities causes direct loss of ecosystems and associated habitat for species, as well as creating impediments to species movement and dispersal across the landscape or otherwise fragmenting habitat. In this ecoregion, urban development that is expected to have impacts on native ecosystems and species is primarily in the form of suburban or exurban growth. Exurban or rural residential development can reduce the quality of a larger expanse of habitat by dotting a previously unaltered landscape with low-density housing and associated roads. Understanding of the specific, direct effects of exurban and rural residential development is still evolving, but research so far indicates that richness of native biodiversity (birds, insects, rodents) often decreases with exurban development (Hansen et al. 2005); where increases in richness occur, it is often due to increases in urban-adapted or non-native species. For rural residential development (e.g., "ranchettes"), the Colorado study summarized indicates that rural residential development was associated with higher numbers and diversity of human-adapted animal species (e.g., European starling (*Sturnus vulgaris*)) and non-native plants, and similarly lower numbers of animal species that are uncommon or of conservation concern and lower numbers of native plant species (Hansen et al. 2005). However, Bock et al.'s (2008) work in southeastern Arizona indicated that exurban development is positively correlated to bird species richness, particularly for the lowest densities of housing; this is attributed to the greater availability of scarce resources, including water, shade, and nest sites, associated with such development.

Other effects of suburban expansion include likely increased fire suppression to protect property, and as a result may further alter fire regimes in adjacent ecosystems. In addition to expansion of suburban development immediately around large metropolitan areas such as Tucson, these areas also generate pressure for further development along transportation corridors that feed into such areas, and other human activities and influences such as recreation, pollution, or noise similarly expand into surrounding areas.

The other major effect of population growth will be the increased demand for water, and the subsequent impacts on aquatic ecosystems, including associated groundwater systems. While water conservation measures have been or are being implemented to varying degrees, current water demand outstrips the rate of replenishment (Callegary et al. 2013). Impacts of water withdrawals on aquatic ecosystems are outlined previously, in the **Water Availability and Altered Hydrology** section above.

Transportation

Transportation corridors include federal and state highways, county and municipal roads, and railroads. Interstate 10 is the major highway cutting through the ecoregion; a section of Interstate 19 also runs through a small portion of the ecoregion. Outside of the Tucson metropolitan area, road density is relatively low. The Southern Pacific railroad line is adjacent to Interstate 10 for much of its length. The Arizona Eastern is the other major railroad line, with portions that adjoin route 70, as well as portions between Safford and Bowie that follow the San Simon River and are not adjacent to any highway corridor.

Primary effects of roads on natural resources include habitat fragmentation, increased wildlife mortality, or hydrologic alterations. Depending on the type of road and individual species, roads may act as complete barriers to animal movement, or features that are avoided to some degree (Coffin 2007, Forman et al. 2003). In some cases, roads may be fenced and prevent animal crossing (e.g., pronghorn and other species in this ecoregion). Road crossings increase mortality and alter adjacent populations for some species (Forman et al. 2003). They may also act as corridors or vectors for the spread of both native and non-native species (Forman et al. 2003). Ecosystem impacts relating to aquatic systems include hydrologic alterations (e.g., alteration of surface water flows), alteration of sediment transport (e.g., increased erosion or increased sedimentation), decreases in water quality, and changes in stream morphology (Coffin 2007).

Energy and Energy Transmission

While this ecoregion has potential for solar, wind, and geothermal energy development, these types of development are not currently present in the Arizona portion of the ecoregion. BLM Arizona's Restoration Design Energy Project (RDEP) includes a single pending wind project in the northwestern-most part of the ecoregion, the 27,000-acre (10,900-ha) Grayback project by Pioneer Green Energy. There are no authorized wind projects, nor pending or authorized solar projects in the Arizona portion of the ecoregion as specified in the RDEP. Although exploration has taken place, there appear to be no active oil or gas wells or geothermal resources based on Arizona's well location map (Rauzi 2012). In the New Mexico portion of the ecoregion, oil and gas and geothermal development are being explored in southern Hidalgo County (Community by Design 2011, NMDGF 2006). One geothermal project (Lightning Dock, by Animas, NM) is present in the New Mexico portion of the ecoregion. The primary energy-related infrastructure currently present in this ecoregion is existing transmission lines.

Aside from the Grayback wind project, the main energy-related infrastructure proposed in this ecoregion are three transmission projects that are planned to carry power from renewable energy sources outside the ecoregion to large metropolitan markets to the west; these are the SunZia, Centennial West, and Southline projects. However, given the potential for renewable energy development in this ecoregion, the effects of such infrastructure may become a greater concern in the future.

The clearing of vegetation associated with the construction and maintenance of transmission corridors results in direct loss of habitat and potential for spread of invasive species (Parendes and Jones 2000). The associated construction and use of access roads may result in the road-related impacts described above (fragmentation, increased mortality). Although avian collisions with anthropogenic structures such as transmission lines can result in mortality, Arnold and Zink's (2011) research suggests such collisions do not have a significant effect on bird population trends.

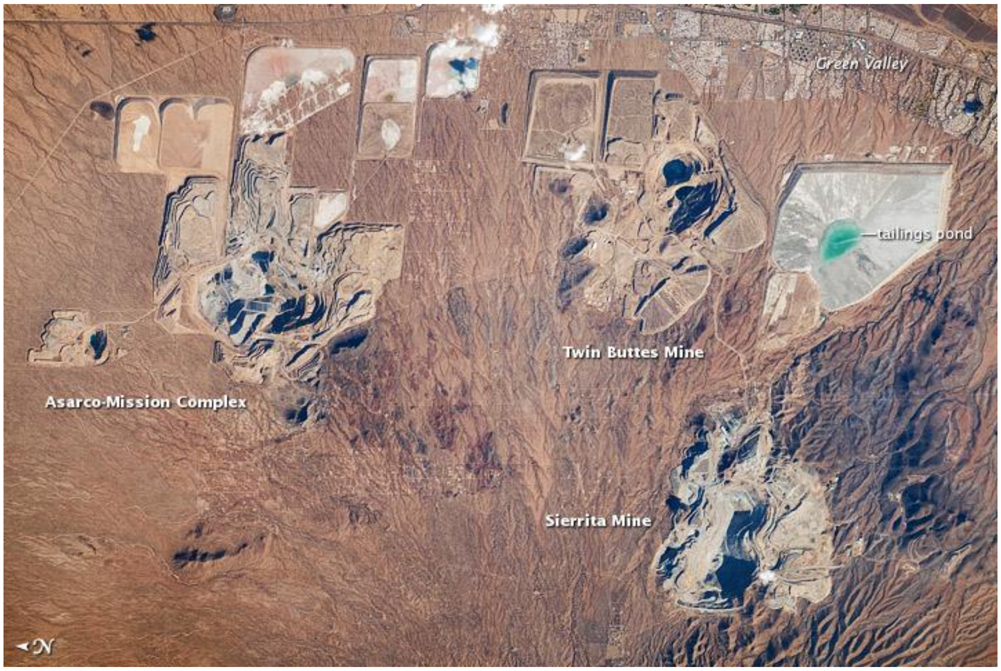
Industry

Mining occurs throughout Arizona and New Mexico. In the MAR ecoregion, there are extensive industrial mining complexes. Mining operations range from large-scale open pit mines to sand and gravel mines and smaller abandoned hard rock mines. Copper mining is one of the largest footprints created by past and current mine operations. About 65 percent of the nation's copper is mined in Arizona and for many years Arizona led the nation in production of nonfuel minerals. In the Arizona portion of the MAR ecoregion, mines are primarily located in mountainous and foothill areas, although some quarry operations are in or near lowland drainages. Major metallic mineral mining districts are primarily polymetallic, producing copper and a combination of lead, zinc and silver (AZGS 2013). In the New Mexico portion of the MAR ecoregion, districts are primarily metallic with two areas of uranium mining (NMBGRM 2008).

In addition to the actual mine footprint and associated habitat loss, activities associated with mines include smelting, land clearing, road and power line building, and disturbance from traffic, noise and lights; as summarized in NMDGF (2006), these activities may result in habitat fragmentation and acid drainage from chemical reactions with surface waste rock that create heavy metal contamination poisonous to wildlife. Mines typically require large quantities of water; for example, 69% of industrial water use in the Tucson Active Management Area is for mining activities (ADWR 2010b). Despite mitigation measures, long periods of operation and abandoned operations with no reclamation still pose a significant impact to biodiversity (AZGFD 2012). Subterranean mine features can eventually become wildlife habitat, particularly for bat species, but may also pose a hazard if activity is renewed after a period of inactivity. Changes in vegetation composition and abundance have been documented near mine facilities (Wood and Nash 1976). Other documented impacts as summarized in the New Mexico Comprehensive Wildlife Strategy (NMDGF 2006) include large permanent pit lakes that contain toxic water and may endanger waterfowl and other bird species, groundwater pollution, air pollution and associated acid-rain fallout, increased frequencies of road-killed fauna, and the potential for bioaccumulation of heavy metals in soils and vegetation at levels dangerous to wildlife (NMDGF 2006).

Extant large mining sites active in the MAR ecoregion include the Clifton-Morenci copper mine, the Asarco Mission Complex, Twin-Buttes Mine, Sierrita Mine (shown in Figure 6-4), and the Queen Mine, among others. Currently, the U.S. Forest Service is receiving an increased number of proposals for exploratory drilling and mine operations, particularly in the Patagonia Mountains; it is currently analyzing a very large proposed copper mine in the Santa Rita Mountains (Coronado National Forest 2013).

Figure 6-4. Aerial view of Asarco Mission Complex, Twin-Buttes Mine, and Sierrita Mine near Green Valley, AZ. Photo courtesy of NASA's Earth Observatory.



For more specifics on the effects of various development features in relation to individual CEs, see the CE conceptual models associated with this report (**Appendices C** and **D**).

6.5.3 International Border: Infrastructure and Activities

As a consequence of its location along the U.S.-Mexico border, the Madrean Archipelago ecoregion experiences a variety of impacts to the ecosystems and species from border-related activities. The international border has a series of physical and virtual barriers along much of its length that are intended to prevent or reduce illegal border crossings. Over 600 miles of physical barriers have been constructed along the nearly 2,000-mile international border. Within the Madrean Archipelago ecoregion, approximately 62% (126 miles) of the roughly 200-mile border is estimated from aerial and on the ground surveys to have some form of barrier infrastructure as of July 2011 (Patrick-Birdwell et al. 2013). Normandy barriers are intended to block vehicular traffic; a variety of virtually impermeable fencing structures, including bollard fencing, mesh fencing, and others, are intended to block pedestrian traffic. These structures are accompanied by major roads and cleared land that can be up to 18 meters (60 feet) wide and an increase in vehicular traffic for construction, enforcement, general public use, and in some places smuggling (Sayre and Knight 2010). In addition to the variety of barrier structures, other border-related infrastructure and activities include security towers, Forward Operating Bases, low-level aircraft flights, and lighting.

Monitoring at Organ Pipe Cactus National Monument (just west of the MAR assessment boundary) and Coronado National Memorial (in the south central portion of the MAR) has indicated that the installation of pedestrian fence and associated roads and concrete footings is impacting the washes that are bisected by them. Impacts include channel aggradation, decreased capacity of the channel to carry flows and sediment, and increased potential for overbanking due to the fence infrastructure trapping debris and effectively creating a dam across channels during specific storm events (Natural Channel Design Inc. 2010). The obstruction of flow and sediment may have major consequences for stream morphology, which may in turn increase the risk of fence failure.

The physical barriers along parts of the border disrupt or prevent the movement of wildlife and water. Construction of these barriers has the potential to drive genetic subdivision in large mammal populations by severing corridors that historically enabled dispersal between Arizona and Mexico sky island ranges (Flesch et al. 2009) and disrupting the movement and gene flow of large carnivores such as mountain lion (*Puma concolor*), jaguar (*Panthera onca*), black bear (*Ursus americanus*), and other large mammals such as pronghorn (*Antilocapra americana*). For example, Atwood et al. (2011) found that additional stretches of pedestrian fence along the international border have the potential to threaten connectivity in areas that may be critically important in facilitating trans-border dispersal of black bears and may predispose segments of the border black bear subpopulation to extinction. It is not known whether Normandy barriers are too wide and high for certain species such as deer to jump over them safely, and they have been documented to change animal behavior (Sayre and Knight 2010). The new roads associated with fence and vehicle barrier construction may have pronounced effects on wildlife. Prey species may be reluctant to cross such a wide cleared area, and roadways provide pathways for invasive species and are providing access to large areas that were previously only reachable on foot. Mesh fencing is impenetrable to much smaller animals as well, such as toads and mice. Ferruginous pygmy owls (*Glaucidium brasilianum*), which prefer to fly at low levels from tree to tree, may avoid crossing fencing that is 15 to 20 feet high (Flesch et al. 2009). Additionally, studies have shown that the erection of barriers and infrastructure to deter human movement has had the effect of channeling this movement into increasingly remote and rugged areas. As illegal migrant apprehensions in urban areas have decreased, apprehensions on land managed by the Department of Interior have increased dramatically.

Border patrol activities have resulted in the construction of a substantial network of roads and high levels of off-road ATV and OHV use in order to access more remote areas, resulting in loss and degradation of vegetation and soil erosion in otherwise relatively untouched habitats. Off-road use of pickup trucks and other large vehicles is associated with smuggling, and camps or lay-up sites dot remote portions of the landscape and result in a significant accumulation of garbage. Aside from the direct issues caused by these illegal activities, off-road driving and camp sites are also expected to impact the condition of ecosystems in this region. Understanding the approximate extent and degree of impact of these activities on the ecoregion's biodiversity is a key concern documented in this phase of the REA. For more specifics on the effects of border-related infrastructure and activities in relation to individual CEs, see the CE conceptual models associated with this report (**Appendices C** and **D**).

6.5.4 Agriculture

In this desert ecoregion, agricultural activities are largely confined to riparian areas or other sources of water. Crops are grown primarily in valleys – either in riparian areas, such as along the San Pedro River, or in valleys without major streams but with groundwater resources, such as the Willcox Basin. Hay, alfalfa, and cotton generate the most income and are common crops in the Arizona portion of the ecoregion; orchard crops such as apples, pecans, and other tree nuts are grown here as well. Chili peppers are the predominant irrigated crop in the New Mexico part of the ecoregion; other crops include corn, alfalfa, milo, cotton, pumpkins, onions, and permanent pasture. Vineyards are also increasing in this ecoregion (J. Ruth, pers. comm. 2013). Farm and other non-rangeland land uses comprise less than 2% of the land uses in this county (Hidalgo County Soil and Water Conservation District Local Work Group 2012). Based on the land cover data, agriculture occupies less than 1.5% of the ecoregion as a whole.

In addition to concerns around water withdrawals for agricultural crops (described previously in the **Water Availability and Altered Hydrology** section), the other major issue around agriculture is the loss of riparian or other habitat where land has been converted to grow crops. Most habitat loss related to agriculture is in riparian or wetland systems; however, vineyards are impacting grassland habitat (e.g., in the Sonoita Valley, J. Ruth, pers. comm.) As summarized in that discussion, riparian habitat is critical for a majority of animal species in arid ecosystems such as the Madrean Archipelago. Riparian habitat is estimated to have historically occupied approximately 1% of the area in the western U.S. as a whole, and 95% of this crucial habitat is calculated to have been lost over the last century to a variety of anthropogenic influences and uses, including unmanaged grazing, stream channelization, agricultural conversion, and other factors (Krueper 1995); these estimates are assumed to be similar for the Madrean Archipelago ecoregion. Although the agricultural footprint is a small proportion of the ecoregion (on the order of 1.5%, based on NatureServe 2013), it occupies a substantial portion of the limited riparian habitat that is found in this ecoregion. ADWR (2010a) notes that on the whole, demand for water for agricultural uses in the Southeastern Arizona Planning Area is increasing, suggesting that agricultural acreage may be increasing; additional agricultural development would cause further habitat losses in an already highly stressed ecosystem. For more specifics on the effects of agriculture in relation to individual CEs, see the CE conceptual models associated with this report (**Appendices C** and **D**).

6.5.5 Management Concerns Around Development and Other Land Uses

Grazing

Given the extent of livestock grazing in this ecoregion, resource managers identified a number of specific information needs relating to grazing. These information needs can be summarized as follows:

1. **What are the past, current, and potential future effects of livestock grazing on the ecological status** (extent, condition (including structure and composition), and function) **of ecosystems, particularly semi-desert grassland and riparian/stream systems?** This group of questions includes understanding impacts to the soils that support these ecosystems.
2. **What are the interacting effects of grazing in conjunction with other CAs?** There is a need to understand the interactions in particularly between grazing and climate change, expansion of native woody species (mesquites), invasion and spread of invasive, non-native grasses, and altered fire regimes – both currently and in the future.
3. **Where might climate change impacts on grassland ecosystems affect the ability to continue grazing?**
4. **Where and how have the effects of grazing on ecosystems affected wildlife species?**
5. **Where has grazing (either historical or present-day) degraded ecosystems to a point where it is not practical to restore them?**
6. **What are the effects of specific grazing-related management or restoration practices on ecosystems and habitats?** There is a need to understand the effects of individual management practices, as well as combinations of treatments, and to identify which treatments are most effective under various conditions.
7. **Where are areas that are not currently grazed, that may have potential to be grazed, particularly as a factor of proximity to existing water development?**

Municipalities, Utilities, Transportation, Industry, Agriculture, and International Border

A number of management issues that were explicitly identified in relation to these infrastructure features, land uses, or activities generally tie back to water usage and availability and impact on aquatic and riparian ecosystems. Water usage for agriculture, municipalities, and industry (primarily mining) and the effects on aquatic ecosystems is a significant concern; see the synthesis of management concerns around water availability and hydrology earlier in this chapter.

Another set of questions around these features is related to their impacts on ecosystems and species aside from their effects on water availability. Questions around this issue comprised a somewhat smaller proportion of all specific questions identified, particularly compared to water and climate-related questions. Each of the questions are directed at the effects of each of the different types of infrastructure and land uses that fall under this broad category of “development,” including urban/residential/commercial development (municipalities), linear infrastructure (roads, transmission lines, etc.), industrial and energy development (e.g., mines, renewable energy projects), border tactical infrastructure (including border patrol roads, barrier/fencing structures, lighting, and forward operating bases), and agriculture; they can generally be characterized as follows:

1. **What are the effects of these features and activities on the status of ecosystems and species? In particular, what are the effects of border-related fencing and roads on stream hydrology?**
2. **What are the effects of these features and activities on habitat fragmentation and connectivity? In particular, what is the effect of border tactical infrastructure and border-related activities on habitat fragmentation and connectivity?**
3. **Where are these features and activities in relation to ecosystems and species?**
4. **Where are these features and activities expected to be constructed or taking place in the future, and what will their effects on the status of ecosystems and species be in the future?**
5. **How will synergies between these features and activities and other CAs (climate change, invasive species, fire) affect the status of ecosystems and species?**
6. **Where are ecosystems and species most vulnerable to these impacts, both now and in the future?**

6.6 Current Issues Relating to the Mexico Portion of the Ecoregion

Although the geospatial analysis for this particular assessment is primarily limited to the U.S. portion of the ecoregion, ecosystems, species, the processes supporting and influencing these resources, and anthropogenic influences on these resources do not heed political jurisdictions. Human population distribution and land uses in the Mexico and U.S. portions of the ecoregion are broadly similar, with most people concentrated in a few larger and numerous smaller municipalities, and grazing and mining being major economic activities (Marshall et al. 2004). Nogales and Agua Prieta are the largest and rapidly growing population centers on the Mexico side; most of the smaller communities are showing downward population trends (Marshall et al. 2004). In contrast to the U.S. portion of the region, the vast majority of land is either privately owned or organized as *ejidos*[4]. Many of the factors affecting species and ecosystems are similar on both sides of the border – water availability, grazing, border activities, invasive or other problematic species, mining impacts, and climate change are of concern on the Mexico side as well (Updike et al. 2013, Marshall et al. 2004).

A number of concerns for biodiversity status and management within the U.S. portion of the ecoregion stem from differences between the two countries’ mining and water laws and natural resources management practices, or other activities or influences that are taking place in or originating from the Mexico portion of the ecoregion. The San Pedro River originates in Sonora, near the municipality of Cananea, while a portion of the upper reach of the Santa Cruz River runs through Sonora near Nogales. Water usage and management in the upper reaches of these rivers affects water quantity and quality for these aquatic ecosystems in their lower reaches on the U.S. side (Sprouse 2005).

The Cananea Copper Mine in Sonora is Mexico’s largest open-pit copper mine and is one of the oldest, opened in 1889. Plans are currently moving forward for an open-pit copper/molybdenum mine and sulfuric acid plant near the Santa Cruz River, nine miles south of the border and 20 miles southeast of Nogales, Sonora. This mining project has prompted inquiries from the Arizona Department of Environmental Quality and the University of Arizona’s Water Resources Research Center due to concerns about potential water and air quality impacts (Kamp D.).

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[4] An ejido is a farm communally owned and operated by the inhabitants of a village on an individual or cooperative basis.

Another concern is around the management of non-native species; for example, resource managers participating in the REA workshops noted that buffelgrass is actively being planted in the Mexico portion of the ecoregion (Brenner and Kanda 2012). With climate change in general, there is concern that invasive pest species such as bark beetles (Bentz et al. 2008; Bentz et al. 2010) may expand their range into the U.S. portion of the ecoregion (regardless of management practices on in the Mexico portion).

Air quality concerns stemming from dust related to grazing, agricultural practices, and mining operations in the Mexican portion of the ecoregion were noted in the MQs and in workshops.

A general concern is how the geographic distribution of ecological systems may shift as a result of climate change, and consequently, how ecological systems in the Mexico portion of the ecoregion might or might not shift into the U.S. portion. Although such climate-driven changes don't originate specifically from resource management practices in the Mexico portion of the ecoregion, the interaction of climate change effects with factors such as buffelgrass planting and associated effects on fire regimes may further complicate vegetation shifts. Modeling of potential climate change effects on distribution of dominant plant species or broad vegetation types would be critical to understanding whether potential vegetation shifts are likely to have a general south-to-north trend, or instead a migration from low elevations to higher elevations, or some combination of the two.

7 Synthesis of Management Concerns: From Management Questions to Proposed REA Assessments

The management questions and issues that were identified in the Development Forums and summarized across various themes such as water availability, climate change, and fire in the Current Issues chapter above have broader commonalities. The questions broadly reflect an overall need to better understand how all of the identified change agents affect the condition (or ecological status) of ecosystem and species CEs, where those effects are occurring, where they may occur in the future, and how the future CAs may alter the condition or status of CEs in the future. In addition, there is a need to understand the interactions and synergies between the CAs, and how those synergies may further affect the ecosystem and species CEs. These management information needs can be further distilled into the following broad and inter-related categories of MQs:

- Where do CAs currently overlap with CEs? Where will they overlap in the foreseeable future?
- What is the current condition or ecological status of ecosystem and species CEs?
- How might the CEs be affected by CAs in the foreseeable future?
- What is the ecological integrity of the ecoregion
- Special assessments that do not easily fit into any of the above categories

A fundamental component of the REAs is documenting the location or spatial extent of CEs and CAs, to the extent permitted by available data or modeling tools. The questions of "Where are the CEs" or "Where are the CAs" are generally not listed as explicit, separate MQs in the list of MQs that informed the scope this REA. However, they are a key component of the REA that will be addressed through the provision of data on those spatial extents. These data sets will form the foundation for analyses conducted for the REA.

Standard, required components of REAs include characterization of the overlap between CEs and CAs, the current and future ecological status of CEs, and overall ecological integrity of the ecoregion. While many of the MQs identified for this REA readily fit into one or more of those categories of standard REA assessments, a number do not. For example, some MQs asked about which management or restoration techniques would be most effective or appropriate under various conditions; while these questions are very important to managers, they are beyond the scope of an REA. One example of this is "How can we "restore" grasslands fragmented by shrub invasion across multiple jurisdictions?" REAs are not designed to provide management recommendations or recommendations for agency collaboration around management issues. The REA can, however, provide information on the current and projected condition of the natural resources, which can then inform management or restoration priorities. In the example of the grasslands restoration question above, the REA will provide information on the current extent and condition of both grasslands and mesquite-dominated shrublands, as well as land ownership patterns; this information lays the groundwork for considering where and how to go about restoration.

In other instances, MQs are more complex questions that address synergistic effects of multiple CAs on each other and on CEs or otherwise did not fit neatly into the above categories, but are still potentially within the scope of an REA; these are broadly categorized as potential "special assessments." For example, "How do invasive grass species such as buffelgrass and cheatgrass affect native fire regimes, intensity, seasonality, and native plant mortality [and what are the impacts on grasslands]?" is an MQ that could be a special assessment; it goes into more depth than the above categories and asks about interactions between CAs and the effects of those interactions on CEs.

Based on the initial review of MQs and issues in the ecoregion, this section provides a broad overview of the major groups of questions that can potentially be addressed in this REA, organized in the categories described above; this in part set the stage for developing the work plan outlining the proposed assessments and how they will be conducted. As noted previously, the complete list of MQs that were identified through the REA pre-assessment scoping process is provided in **Appendix B**. Examples of MQs that are highlighted in this chapter are followed by a number in parentheses, indicating the MQ # as shown in **Appendix B**.

Also noted above, the separate work plan (Crist et al. 2013) developed for this REA includes an overview of each of the individual proposed assessments and a proposed approach for conducting them.

7.1 Intersection of Change Agents and Conservation Elements

Understanding the patterns of spatial overlap between CAs and CEs is one of the most basic requested categories of MQs. While a basic data intersection does not model CA effects on CEs, it allows users to quickly conduct a visual and quantitative evaluation of the potential for the CA to impact the CE. Examples of questions relating to CE/CA overlap include the following (numbers in parentheses reference the MQ # in the MQ table provided in **Appendix B**):

- Where are existing and potential energy development (oil, gas, mineral, solar, wind, geothermal, biomass, bioenergy, other renewables) and associated infrastructure (roads, ROWs, etc.) and what is their proximity to resources of high conservation and/or restoration potential? (182)
- Where will regionally significant values be at risk from wildland fire? (168)

7.2 Ecological Status Questions

Assessing the ecological status or condition of CEs is one of the major required components of an REA; status will be evaluated for all of the CEs selected for this REA. The CE conceptual models describe the ecosystem processes that shape them, the range of variability of these processes, and the defining characteristics of the CE, as well as a suite of indicators that can be evaluated to determine ecological status. The information contained in the conceptual models guides the associated analysis of the CE indicators response to CAs to characterize ecological status. The status results will address or lay the groundwork for addressing numerous MQs. Examples of questions proposed by REA participants, which relate directly to current ecological status assessments, include the following (numbers in parentheses reference the MQ # in the MQ table provided in **Appendix B**):

- Where are riparian, wetland habitats and what are their current conditions and trends? (151)
- Where are landscapes/communities/watersheds with high biotic integrity? (156)
- Which areas are sustaining Madrean woodlands through natural or prescribed fires? Which areas have departed from historical fire regimes? (21)
- What is the loss of historical semi-desert grassland plant community structure and function due to climate change and other CAs? (7)
- What is the role of fire across the landscape? (22)
- Where and how are livestock management practices impacting habitats for key landscape wildlife species? (15)
- How have regionally significant species and habitat connectivity been affected by Department of Homeland Security (DHS)/U.S. Customs and Border Protection (CBP) infrastructure (e.g., border fence, border roads, tire drag areas) and associated activities? (187)

A number of questions relating to projected ecological status were also identified. Examples of MQs relating to future ecological status include the following:

- Where will the trend (historical to present to future) of wildland fire change (frequency, severity, and seasonality) in the different regionally significant community types? (169)
- Where will landscapes/communities/watersheds most likely be affected by changes in the spatial distribution and abundance of invasive species due to CAs (climate change, wildland fire, anthropogenic disturbances)? (176)
- What is the degree of vulnerability of species CEs to projected climate change and where will the most vulnerable species CEs experience significant changes in driving climatic variables? (197)

7.3 Ecological Integrity

Assessing the ecological integrity of the ecoregion as a whole is another major required component of an REA. The ecoregion conceptual model provided in this report describes the drivers and ecosystem processes that shape the biota of the ecoregion as a whole, as well as a suite of potential indicators that can be evaluated to determine ecological integrity. The ecological integrity results will provide a summary of the state of the ecoregion, and the related outputs may also be used to address or lay the groundwork for addressing numerous MQs. Examples of questions proposed by REA participants, which relate directly to ecological integrity, include the following (numbers in parentheses reference the MQ # in the MQ table provided in **Appendix B**):

- Where are landscapes/communities/watersheds with high biotic integrity? (156)
- Where are current “at risk” areas (limited connectivity, small size, imminent threat from change agents, introduction of disease and/or disease vectors)? (157)

7.4 Special Assessments

As noted above, “standard” REA assessments include basic characterization of CE and CA distribution, the overlap between CEs and CAs, the current and future ecological status of CEs, and overall ecological integrity of the ecoregion. Many MQs identified for this REA would require assessments that go beyond the standard REA assessments; these questions are categorized as “special assessments.” Special assessments do not fit neatly into the above MQ categories but may otherwise still be within the purview of an REA. Examples include the following (numbers in parentheses reference the MQ # in the MQ table provided in **Appendix B**):

- How do border control activities (such as fences, roads, vehicle barriers, and traffic) affect movement of terrestrial mammals (such as pronghorn, mule deer, jaguars?) and will immigration reform improve border habitat connectivity? (42)
- How have aquatic systems changed from pre-European levels? ***Reframed as*** How has the spatial extent of perennial flows, marshes, riparian gallery forest, and ciénegas changed since the mid-1800s? (64)

Of particular note with regard to special assessments is the Apacherian-Chihuahuan Mesquite Upland Scrub system. Since resource managers are concerned primarily with the potential for and value of restoring it back to semi-desert grassland, as well as how its distribution may continue to expand under climate change, any assessments around this type will fall into the special assessment category, rather than the standard ecological status assessments planned for CEs.

8 Annotated Bibliography

ADWR [Arizona Department of Water Resources]. 2010a. Arizona Water Atlas, Volume 3: Southeastern Arizona Planning Area. Arizona Department of Water Resources, Phoenix, AZ. (Available on-line at http://www.azwater.gov/azdwr/statewideplanning/wateratlas/.)

REA Key Words: Current Environment, Landscape Assessment

This atlas has excellent overview of the location and hydrologic character of rivers and river basins, covers groundwater and surface water sources, known threats and water use issues, as well as water quality issues. Also summarized are landscape features, geology, vegetative cover, land ownership, human population centers and census information. Each volume covers a different part of the state of Arizona. Volume 3 covers southeastern Arizona, largely overlapping with the Arizona portion of the Madrean Archipelago ecoregion.

AZGFD [Arizona Game and Fish Department]. 2012. Arizona's State Wildlife Action Plan: 2012-2022. Arizona Game and Fish Department, Phoenix, Arizona.

REA Key Words: Current Environment, Landscape Assessment, Conservation Elements

Arizona's State Wildlife Action Plan (SWAP) provides a comprehensive vision for managing Arizona's fish, wildlife and wildlife habitats for a 10-year period. The plan outlines strategies and conservation actions aimed at promoting partnerships and coordinating efforts among stakeholders in conserving Arizona's wildlife. While the plan addresses the full array of wildlife and habitats, it focuses on identifying and managing the wildlife and habitats that are in the greatest need of conservation.

Bodner, G., J.A. Montoya, R. Hansen, and W. Anderson. Natural Heritage of the Peloncillo Mountain Region: A Synthesis of Science. Sky island Alliance and World Wildlife Fund. 166 pp.

REA Key Words: Landscape Assessment, Conservation Elements

This report documents the unique and impressive biological diversity and ecosystems of the Peloncillo region located in southeastern Arizona, southwestern New Mexico, northeastern Sonora and northwestern Chihuahua. The report amasses expert knowledge and sets a framework for conservation. It covers earth forces and living systems, birds, fishes, herpetofauna, invertebrates, mammals and vegetation.

Dinerstein, E., D. Olson, J. Atchley, C. Loucks, S. Contreras-Balderas, R. Abell, E. Iningo, E. Enkerlin, C. E. Williams, and G. Castilleja. 2000. Ecoregion-Based Conservation in the Chihuahuan Desert. World Wildlife Fund, Comision Nationa para el Conocimiento y Uso de la Biodiversidad, The Nature Conservancy, PRONATURA Noreste, and the Instituto Tecnologico y de Estudios Superiores de Monterrey. 158 p.

REA Key Words: Landscape Assessment, Current Environment

This collaborative effort applied an ecoregion-based conservation approach to identify 61 candidate sites that would conserve the full range of species, natural communities, habitats, and ecological processes characteristic of the Chihuahuan ecoregion (of which the Madrean Archipelago ecoregion is a part). Terrestrial experts used biological distinctiveness and landscape integrity to prioritize 16 terrestrial sites and evaluated and scored threats to those sites, and identified conservation efforts that can be undertaken immediately.

Enquist, C. and D. Gori. 2008. Implications of Recent Climate Change on Conservation Priorities in New Mexico. The Nature Conservancy. 49 pp.

REA Key Words: Climate Change, Landscape Assessment, Current Environment

This state-wide assessment of recent climate changes is designed to enable practitioners and managers to make better informed decisions by identifying the potential vulnerability of habitat types, priority conservation sites and species to climate change. The authors identified conservation sites that may be vulnerable to climate changes, areas of lower climate change exposure and compiled 48 cases of recently observed ecological changes that may be linked to climate change from across New Mexico and the southwestern U.S.

Enquist C., E.H. Girvetz, D.F. Gori. 2008. Conservation Implications of Emerging Moisture Stress Due to Recent Climate Changes in New Mexico. The Nature Conservancy. 20 pp.

REA Key Words: Climate Change, Current Environment

This report uses a combined temperature-precipitation variable, termed the *climate water deficit*, to map and analyze recent trends (1970-2006). ClimateWizard was used to generate and summarize water deficit trends by watersheds, which were combined with trends in snowpack and the timing of peak streamflows to further examine the physical implications of regional climate change. Climate water deficit (i.e., moisture stress) in watersheds was then related to the number of species with conservation status occurring within them in order to evaluate conservation implications.

Gori, D., G. S. Bodner, K. Sartor, P. Warren, and S. Bassett. 2012. Sky Island Grassland Assessment: Identifying and Evaluating Priority Grassland Landscapes for Conservation and Restoration in the Borderlands. Report prepared by The Nature Conservancy in New Mexico and Arizona. 85 p.

REA Key Words: Landscape Assessment, Current Environment

In order to identify priority grassland landscapes for focusing conservation investment to restore grassland health and recover target wildlife species, this study brought together and synthesized data from the Apache Highlands Grassland Assessment, the New Mexico Rangeland Assessment, land cover data from the Instituto Nacional de Estadistica y Geographia, and information on the distribution of sensitive grassland and riparian/aquatic species. Spatial data was combined with input from experts in the U.S. and Mexico to identify a network of 12 priority grassland areas that succeed in capturing many of the target biological. The report summarizes the information for each of the twelve priority grassland landscapes including size, condition, connectivity with other priority landscapes, embedded riparian wetland habitats, sensitive species, threats, land management responsibility, protected status and human enabling conditions that contribute to the feasibility of future conservation efforts.

Gori, D. F., and C. A. F. Enquist. 2003. An Assessment of the Spatial Extent and Condition of Grasslands in Central and Southern Arizona, Southwestern New Mexico and Northern Mexico. Prepared by The Nature Conservancy, Arizona Chapter. 28 pp.

REA Key Words: Current Environment, Landscape Assessment

This report assesses and characterizes the extent and location of vegetation changes to grasslands and identifies the best remaining native grasslands and restorable grasslands for conservation planning and ecological management purposes. The authors used an expert input process complemented by field reconnaissance and quantitative vegetation sampling at random sampling points. Vegetation change in grasslands has been extensive and dramatic including shrub encroachment and the spread of non-native perennial grasses. Most native grasslands have no legal protective status which would prevent conversion or clearing of their natural land cover.

Heinz Center. 2011. Managing and monitoring Arizona's wildlife in an era of climate change: Strategies and tools for success. Report and Workshop Summary, The H. John Heinz III Center for Science, Economics and the Environment, Washington, D.C. 67p plus appendices.

REA Key Words: Climate Change, Landscape Assessment, Current Environment

This report is focused on climate change impacts in Arizona. To assist managers in responding to climate change, the report introduces the concept of an integrated wildlife monitoring program for the state of Arizona. Monitoring programs have the potential to provide information about early effects of climate change on ecosystems, and guide adaptation and mitigation responses. This report explains the steps required to develop an integrated monitoring approach, from conceptual modeling and indicator selection to sampling design and data management. It also includes information about existing monitoring programs in the state of Arizona that are capturing important information about key species and ecosystems of management interest. The Heinz Center co-sponsored a “Pioneering Performance Measures” workshop with the Bureau of Land Management and the Arizona Game and Fish Department to gather wildlife and land stakeholders from throughout the state and help build consensus on shared priorities and common conservation targets. The results from the workshop include conceptual models for target ecosystems such as the Sonoran Desert, lists of candidate indicators for the target ecosystems, and lists of existing monitoring programs.

Marshall, R.M., D. Turner, A. Gondor, D. Gori, C. Enquist, G. Luna, R. Paredes Aguilar, S. Anderson, S. Schwartz, C. Watts, E. Lopez, and P. Comer. 2004. An Ecological Analysis of Conservation Priorities in the Apache Highlands Ecoregion. Prepared by The Nature Conservancy of Arizona, Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora, agency and institutional partners. 152 pp.

REA Key Words: Landscape Assessment, Current Environment, Conservation Elements

A bi-national team used the computer algorithm SITES to identify a network of conservation areas that, with proper management, would ensure the long-term persistence of the Apache Highland Ecoregion’s biological diversity. Twenty-six terrestrial ecological systems and 223 species were selected as focal units of analysis. Analysis included developing numerical conservation goals for all targets and utilized a variety of spatial and traditional data sets. The final network consists of 90 conservation areas encompassing just over 12.5 million acres (5 million ha).

Mau-Crimmins, T., A. Hubbard, D. Angell, C. Filippone, N. Kline. 2005. Sonoran Desert Network Vital Signs Monitoring Plan. Technical Report NPS/IMR/SODN-003. National Park Service. Denver, CO.

REA Key Words: Current Environment, Landscape Assessment

The primary goal of the National Park Service (NPS) Inventory and Monitoring (I&M) Program is to assess the long-term ecological condition of the park units, evaluate resource response to management actions, and facilitate effective resource management. The Sonoran Desert Network (SODN) is one of 32 NPS I&M Networks established to implement this program. This SODN Monitoring Plan summarizes the activities undertaken to develop the monitoring program, incorporates the products of two earlier phases, and serves as the final monitoring plan. The SODN includes park units within the Madrean Archipelago REA boundaries. This report provides an overview of the major ecosystems and change agents within the SODN, based on detailed inventory and survey of the scientific literature. It provides conceptual models for the Network as a whole and for individual major ecosystems. Existing and desired monitoring efforts by various agencies are profiled. The SODN selected 25 “vital signs” to form the basis of their monitoring program, and the report outlines the Network’s intent for sampling designs, data management and archiving, data analysis and reporting, administration and implementation of the plan,

as well as a budget and schedule. It contains extensive appendices, including monitoring protocols for each vital sign.

Milchunas, D. G. 2006. Responses of plant communities to grazing in the southwestern United States. Gen. Tech. Rep. RMRS-GTR-169. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 126 p.

REA Key Words: Grazing

This review summarizes and interprets the literature on livestock grazing effects on 25 plant communities found in the desert southwest. It characterizes impacts in relation to plant species composition, aboveground primary productivity, and root and soil attributes. It includes historical context on past grazing practices and considers potential differences in grazing impacts between ecosystems with an evolutionary history of large-herbivore grazing (Great Plains and eastern prairies) and those without (southwestern U.S. ecosystems).

NMDGF [New Mexico Department of Game and Fish]. 2006. Comprehensive Wildlife Conservation Strategy for New Mexico. New Mexico Department of Game and Fish. Santa Fe, NM. 526 pp + appendices.

REA Key Words: Current Environment, Landscape Assessment, Conservation Elements

New Mexico's State Wildlife Action Plan describes an ecologically based approach for strategic actions to conserve wildlife. It provides a framework for conserving biological diversity in New Mexico in context with surrounding areas. It characterizes the biodiversity of the state and identifies species and habitats warranting conservation actions. It organizes existing information and summarizes where important information gaps remain.

NMOSE [New Mexico Office of the State Engineer] 2008. New Mexico Water Use by Categories 2005. Prepared by J.W. Longworth, J.M. Valdez, M.L. Magnuson, E.S. Albury and J. Keller. Technical Report 52, June 2008, Santa Fe, NM.

REA Key Words: Current Environment

This document defines the water use categories and the quantitative methods for calculating water use, by county and by river basin for the state of New Mexico. It differs from previous reports in that it no longer calculates the loss from withdrawals due to evaporation or leakage ("depletions"). It does not attempt any descriptive narrative of the landscape, water sources or climate of New Mexico.

Robles, M.D. and C. Enquist. 2010. Managing changing landscapes in the Southwestern United States. The Nature Conservancy. Tucson, Arizona. 26 pp.

REA Key Words: Landscape Assessment, Current Environment

Focused on the southwest states of Arizona, New Mexico, Utah and Colorado, this report evaluates changes in annual average temperatures from 1951–2006 across major habitats and large watersheds and compares these changes to the number of species of conservation concern that are found within these places. The authors found that ninety percent of habitats in the Southwest have warmed significantly in the past 55 years. The report also details actionable recommendations developed at workshops with scientists and managers designed to bolster health and resilience of natural resources.

Stromberg, J. C. and B. Tellman (eds). 2009. Ecology and Conservation of the San Pedro River, University of Arizona Press.

REA Key Words: Landscape Assessment, Current Environment

This volume contains detailed technical chapters on research into the patterns and processes of the San Pedro River vegetation, hydrology, animal use, and ecology, as well as threats and conservation efforts. It provides the contextual background and summarizes research activity in the San Pedro Basin.

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10 Glossary

Analysis unit: An analysis unit is the spatial unit of analysis for ecoregional assessment and is the smallest area analyzed and used for regional planning purposes. The analysis units for ecoregional analysis may be a regular size and shape (e.g., square, hexagon) but also may be defined by a particular level of hydrologic unit or similar geographic feature.

Areas of Critical Environmental Concern (ACEC): Areas within the public lands where special management attention is required to protect and prevent irreparable damage to important historical, cultural, or scenic values, fish and wildlife resources or other natural systems or processes, or to protect life and safety from natural hazards (per the Federal Land Policy and Management Act of 1976).

Assessment Management Team (AMT): BLM's team of BLM staff and partners that provides overall guidance to the REA regarding ecoregional goals, resources of concern, conservation elements, CAs, MQs, tools, methodologies, models, and output work products. The team generally consists of BLM State Resources Branch Managers from the ecoregion, a point of contact (POC), and a variety of agency partners depending on the ecoregion.

Attribute: A defined characteristic of a geographic feature or entity.

Change Agent (CA): An environmental phenomenon or human activity that can alter/influence the future status of resource condition. Some CAs (e.g., roads) are the result of direct human actions or influence. Others (e.g., climate change, wildland fire, or invasive species) may involve natural phenomena or be partially or indirectly related to human activities.

Coarse Filter: A focus of ecoregional analysis that is based upon conserving resource elements that occur at coarse scales, such as ecosystems, rather than upon finer scale elements, such as specific species. The concept behind a coarse filter approach is that preserving coarse-scale conservation elements will preserve elements occurring at finer spatial scales.

Community: Interacting assemblage of species that co-occur with some degree of predictability and consistency.

Conservation Element (CE): A renewable resource object of high conservation interest often called a conservation target by others. For purposes of this TO, conservation elements will likely be types or categories of areas and/or resources including ecological communities or larger ecological assemblages.

Development: A type of change (CA) resulting from urbanization, industrialization, transportation, mineral extraction, water development, or other non-agricultural/silvicultural human activities that occupy or fragment the landscape or that develops renewable or non-renewable resources.

Ecological Integrity: The ability of an ecological system to support and maintain a community of organisms that have the species composition, diversity, and functional organization comparable to those of natural habitats within the ecoregion.

Ecological Status: The condition of a criterion (biological or socio-economic resource values or conditions) within a geographic area (e.g., watershed, grid). A rating (e.g., low, medium, or high) or ranking (numeric) is assigned to specific criteria to describe status. The rating or ranking will be relative, either to the historical range of variability for that criterion (e.g., a wildland fire regime criterion) or relative to a time period when the criterion did not exist (e.g., an external partnerships/collaboration criterion). (also see *Status)*

Ecological system: In this report, ecological systems are defined as groups of plant communities that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients; the term is used to refer to ecological systems as classified by Nature Serve (Comer et al. 2003) and mapped by NatureServe (2013)

Ecoregion: An ecological region or ecoregion is defined as an area with relative homogeneity in ecosystems. Ecoregions depict areas within which the mosaic of ecosystem components (biotic and abiotic as well as terrestrial and aquatic) differs from those of adjacent regions (Omernik and Bailey 1997).

Ecosystem: The interactions of communities of native fish, wildlife, and plants with the abiotic or physical environment.

Element Occurrence: A term used by Natural Heritage Programs. An element occurrence generally delineates the location and extent of a species population or ecological community stand, and represents the geo-referenced biological feature that is of conservation or management interest. Element occurrences are documented by voucher specimens (where appropriate) or other forms of observations. A single element occurrence may be documented by multiple specimens or observations taken from different parts of the same population, or from the same population over multiple years.

Extent: The total area under consideration for an ecoregional assessment. For the BLM, this is a CEC Level III ecoregion or combination of several such ecoregions plus the buffer area surrounding the ecoregion.

Fine Filter: A focus of ecoregional analyses that is based upon conserving resource elements that occur at fine scale, such as specific species. A fine-filter approach is often used in conjunction with a coarse-filter approach (i.e., a coarse-filter/fine-filter framework) because coarse filters do not always capture some concerns, such as when a listed threatened or endangered species is a conservation element.

Fire Regime: Description of the patterns of fire occurrences, frequency, size, severity, and sometimes vegetation and fire effects as well, in a given area or ecosystem. A fire regime is a generalization based on fire histories at individual sites. Fire regimes can often be described as cycles because some parts of the histories usually get repeated, and the repetitions can be counted and measured, such as fire return interval (NWCG 2006).

Fragmentation: The separation or division of habitats by intervening infrastructure (e.g., roads or utility corridors) or anthropogenic land uses (development, agriculture); as patches of habitat are increasingly divided into smaller and smaller units or increasingly isolated from other patches of habitat, their utility as habitat may be lost.

Geographic Information System (GIS): A computer system designed to collect, manage, manipulate, analyze, and display spatially referenced data and associated attributes.

Grid Cell: When used in reference to raster data, a grid cell is equivalent to a pixel (also see *pixel*). When a raster data layer is converted to a vector format, the pixels may instead be referred to as grid cells.

Habitat: A place where an animal or plant normally lives for a substantial part of its life, often characterized by dominant plant forms and/or physical characteristics.

Heritage: See *Natural Heritage Program.*

Heritage Program: See *Natural Heritage Program.*

Hydrologic Unit: An identified area of surface drainage within the U.S. system for cataloging drainage areas, which was developed in the mid-1970s under the sponsorship of the Water Resources Council and includes drainage-basin boundaries, codes, and names. The drainage areas are delineated to nest in a multilevel, hierarchical arrangement. The hydrologic unit hierarchical system has four levels and is the theoretical basis for further subdivisions that form the *watershed boundary dataset* containing the 5th and 6th levels. (USGS and NRCS 2009).

Indicator: Components of a system whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute (e.g., land health) that are too difficult, inconvenient, or expensive to measure (NRCS et al. 2005).

Inductive Model: Geo-referenced observations (e.g., known observations of a given species) are combined with maps of potential explanatory variables (climate, elevation, landform, soil variables, etc.). Statistical relationships between dependent variables (observations) and independent explanatory variables are used to derive a new spatial model.

Invasive Species: Species that are not part of (if exotic non-natives), or are a minor component of (if native), an original community that have the potential to become a dominant or co-dominant species if their future establishment and growth are not actively controlled by management interventions, or that are classified as exotic or noxious under state or federal law. Species that become dominant for only one to several years (e.g., in a short-term response to drought or wildfire) are not invasives (modified from BLM Handbook 1740-2, Integrated Vegetation Handbook; see http://www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_handbook.Par.59510.File.dat/H-1740-2.pdf).

Key Ecological Attribute (KEA): An attribute, feature, or process that defines and characterizes an ecological community or system or entity; in conjunction with other key ecological attributes, the condition or function of this attribute or process is considered critical to the integrity of the ecological community or system in question. In the BLM REAs, various analyses will be conducted to calculate scores or indexes indicating the status of key ecological attributes for various Conservation Elements (CEs).

Landscape Species: Biological species that use large, ecologically diverse areas and often have significant impacts on the structure and function of natural ecosystems (Redford et al. 2000).

Landscape Unit: Because an REA considers a variety of phenomena, there will be many phenomena and process (or intrinsic) grain sizes. These will necessarily be scaled to a uniform support unit, which herein is called a *landscape unit*. This landscape unit will be the analysis scale used for reporting and displaying ecoregional analyses.

Management Questions: Questions from decision-makers that usually identify problems and request how to fix or solve those problems.

Metadata: The description and documentation of the content, quality, condition, and other characteristics of geospatial data.

Model: Any representation, whether verbal, diagrammatic, or mathematical, of an object or phenomenon. Natural resource models typically characterize resource systems in terms of their status and change through time. Models imbed hypotheses about resource structures and functions, and they generate predictions about the effects of management actions. (Adaptive Management: DOI Technical Guide, Williams et al. 2009; see http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf).

Native Plant and Animal Populations and Communities: Populations and communities of all species of plants and animals naturally occurring, other than as a result of an introduction, either presently or historically in an ecosystem (BLM Manual H-4180-1; see http://www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_manual.Par.23764.File.dat/4180.pdf).

Native Species: Species that naturally occur in a particular geographic area and were not introduced by humans.

Natural Community: An assemblage of plant species or other organisms native to an area that is characterized by distinct combinations of species occupying a common ecological zone and interacting with one another.

Natural Heritage Program: An agency or organization, usually based within a state or provincial natural resource agency, whose mission is to collect, document, and analyze data on the location and condition of biological and other natural features (such as geologic or aquatic features) of the state or province. These programs typically have particular responsibility for documenting **at-risk species and threatened ecosystems. (See natureserve.org/ for additional information on these programs.)**

Occurrence: See *Element Occurrence*.

Pixel: A pixel is a cell or spatial unit comprising a raster data layer; within a single raster data layer, the pixels are consistently sized; a common pixel size is 30 x 30 meters square. Pixels are usually referenced in relation to spatial data that are in raster format. In this REA, some pixels sizes included 30 x 30 m and 2 x 2 km (also see *Grid Cell*).

Population: Individuals of the same species that live, interact, and migrate through the same niche and habitat.

Rapid Ecoregional Assessment (REA): The methodology used by the BLM to assemble and synthesize that regional-scale resource information, which provides the fundamental knowledge base for devising regional resource goals, priorities, and focal areas, on a relatively short time frame (within 2 years).

Resource Value: An ecological value, as opposed to a cultural value. Examples of resource values are those species, habitats, communities, features, functions, or services associated with areas with abundant native species and few non-natives, having intact, connected habitats, and that help maintain landscape hydrologic function. Resource values of concern to the BLM can be classified into three categories: native fish, wildlife, or plants of conservation concern; regionally important terrestrial ecological features, functions, and services; and regionally important aquatic ecological features, functions, and services.

Scale: Refers to the characteristic time or length of a process, observation, model, or analysis. ***Intrinsic scale*** refers to the scale at which a pattern or process actually operates. Because nature phenomena range over at least nine orders of magnitude, the intrinsic scale has wide variation. This is significant for ecoregional assessment, where multiple resources and their phenomena are being assessed. ***Observation scale***, often referred to as sampling or measurement scale, is the scale at which sampling is undertaken. Note that once data are observed at a particular scale, that scale becomes the limit of analysis, not the phenomenon scale. ***Analysis*** or ***modeling scale*** refers to the resolution and extent in space and time of statistical analyses or simulation modeling. ***Policy scale*** is the scale at which policies are implemented and is influenced by social, political, and economic policies.

Scaling: The transfer of information across spatial scales. ***Upscaling*** is the process of transferring information from a smaller to a larger scale. ***Downscaling*** is the process of transferring information to a smaller scale.

Status: The condition of a criterion (biological or socio-economic resource values or conditions) within a geographic area (e.g., watershed, grid). A rating (e.g., low, medium, or high) or ranking (numeric) is assigned to specific criteria to describe status. The rating or ranking will be relative, either to the historical range of variability for that criterion (e.g., a wildland fire regime criterion) or relative to a time period when the criterion did not exist (e.g., an external partnerships/collaboration criterion).

Step-Down: A step-down is any action related to regionally defined goals and priorities discussed in the REA that are acted upon through actions by specific State and/or Field Offices. These step-down actions can be additional inventory, a finer-grained analysis, or a specific management activity.

Stressor: A factor causing negative impacts to the biological health or ecological integrity of a CE. Factors causing such impacts may or may not have anthropogenic origins. In the context of the REAs, these factors are generally anthropogenic in origin.

Subwatershed: A subdivision of a *watershed*. A *subwatershed* is the 6^{th}-level, 12-digit unit and smallest of the hydrologic unit hierarchy. Subwatersheds generally range in size from 10,000 to 40,000 acres. (USGS 2009).

Value: See *resource value*.

Watershed: A watershed is the 5^{th}-level, 10-digit unit of the hydrologic unit hierarchy. Watersheds range in size from 40,000 to 250,000 acres. Also used as a generic term representing a drainage basin or combination of hydrologic units of any size. (USGS 2009).

Watershed Boundary Dataset (WBD): A national geospatial database of drainage areas consisting of the 1^{st} through 6^{th} hierarchical hydrologic unit levels. The WBD is an ongoing multiagency effort to create hierarchical, integrated hydrologic units across the U.S. (USGS 2009).

Wildland Fire: Any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined and include wildfire, wildland fire use, and prescribed fire (NWCG 2006).

11 List of Acronyms

Not all acronyms listed here have yet been applied in this REA; however, those listed have been commonly used in other REAs and so are included here.

AADT	Annual Average Daily Traffic
ACEC	Area of Critical Environmental Concern
AMT	Assessment Management Team
AR4	International Panel on Climate Change - Fourth Assessment Report
BLM	Bureau of Land Management
CA	Change Agent
CCVI	Climate Change Vulnerability Index
CE	Conservation Element
COR	Contracting Officer Representative
CVS	Conservation Value Summary
CWNA	Climate Western North America
DEM	Digital Elevation Model
DMP	Data Management Plan
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
EIA	Ecological Integrity Assessment
EIS	Environmental Impact Statement
EO	Element Occurrence
EPCA	Energy Policy and Conservation Act
ESA	Endangered Species Act
ESA	Ecological Status Assessment
ESD	Ecological Site Description
FO	Field Office
FRI	Fire Return Interval
GA	Grazing Allotment
GCM	General Circulation Model
GIS	Geographic Information System
HMA	Herd Management Area
HRV	Historical Range of Variation
HUC	Hydrologic Unit Code
ILAP	Integrated Landscape Assessment Project
IPCC	Intergovernmental Panel on Climate Change
KEA	Key Ecological Attribute
LCM	Landscape Condition Model
LF	LANDFIRE (Landscape Fire and Resource Management Planning Tools)
MAR	**M**adrean **Ar**chipelago
MLRA	Major Land Resource Area
MQ	Management Question
MRDS	Mineral Resource Data System
NHD	National Hydrography Dataset

NHNM	Natural Heritage New Mexico
NOC	BLM's National Operations Center
NPMS	National Pipeline Mapping System
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRV	Natural Range of Variability
NTAD	National Transportation Atlas Database
NWI	National Wetland Inventory
ORV	Off-road Vehicle
PRISM	Parameter-elevation Regressions on Independent Slopes Model
REA	Rapid Ecoregional Assessments
REAWP	Rapid Ecoregional Assessment Work Plan
RegCM	International Centre for Theoretical Physics Regional Climate Model
ROC	Receiver Operating Characteristic
SDM	Species Distribution Model
SDR	Southwest Decision Resources
SIA	Sky Island Alliance
SOW	Statement of Work (for REA contract)
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
SWAP	State Wildlife Action Plan
TWI	Topographic Wetness Index
USFWS	U.S. Fish and Wildlife Service
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

Appendix A Detailed Methodology and Rationale

The goal of this appendix is to provide a greater level of detail on the specifics of the approach that was taken to conduct various aspects of the pre-assessment and more information on the rationale behind various decisions made in this phase of the REA. In this manner, interested readers who were not involved or had limited involvement in this task can better understand how decisions were reached. In a number of areas, the direction provided in the Statement of Work and the overall project scope and budget in part informed some of the decisions that were made; this is noted where relevant as well.

A.1 Conceptual Model Development

A.1.1 Ecoregion and Ecological Integrity Conceptual Models

The development of the content for ecoregional conceptual model was completed by several topic experts on the contracting team. Expertise on the team includes wildlife, vegetation and riparian ecologists, conservation planners, landscape ecologists, invasive species experts, climate effects modeler, geohydrologist, fire ecologist, and local expertise from biologists and ecologists with Sky Island Alliance. In addition, the BLM and AMT contributed via recommending reports and literature to consult.

Many large-scale assessments have already been completed for this ecoregion, and the larger Sonoran or Chihuahuan Desert regions within which it lies. The sky island region has also been the focus of several conferences devoted to the biodiversity, ecology, landscape ecology, fire ecology and conservation of the region. All of these assessment documents and reports were consulted for general and specific information for components of the descriptive portion of the ecoregion conceptual model.

There is also a wealth of published papers, books, and reports related to all or portions of the MAR ecoregion, and the species, ecosystems, and stressors occurring in the ecoregion. Many of these are cited in the previously mentioned assessment documents, while others are more recent.

Content development was assigned to the team members according to expertise to match the various topics to be covered in this report. Much of the available literature was already known to the team members, and the AMT provided additional suggestions. Each section was completed by the assigned team member, added to the report, and then was reviewed by one or more others. Additional editing for consistency and to remove as much redundancy as possible was completed after all content was added.

A.1.2 Conservation Element Conceptual Models

Ecosystem CEs

Conceptual models developed for this REA combine text, concept diagrams, and tabular summaries in order to clearly state assumptions made about the ecological composition, structure, dynamic processes, and interactions with major CAs within the ecoregion. These conceptual models will inform the development of spatial models for assessing the relative ecological status of each CE. Methods for developing content included for each CE conceptual model is described below.

The descriptive material builds upon the descriptions for terrestrial ecological systems that NatureServe has and serves on its website (http://www.natureserve.org/explorer/index.htm) to search and download existing descriptions. For this REA, additional material was added for each ecosystem CE, especially focusing on content describing natural and altered vegetation dynamics, as well as threats and stressors to the system. Additional material was added for each wetland CE, focusing on adding aquatic components, and describing natural and altered dynamics, as well as threats and stressors to the system. The information developed is intended to cover the full range of distribution of the CEs, which can extend beyond the ecoregion, and does not specifically focus on its characteristics or dynamics as they occur within this ecoregion.

In general, the basic method for finding and adding information to that previously developed by NatureServe is to survey the scientific literature, initiated through searching on key words on the internet. The team pursued resulting lists of publications that were determined to be either appropriate peer-reviewed journal articles or technical or other reports compiled by federal or state agencies, or NGOs. In these searches and reviews of publications, key or seminal works or major literature reviews could be identified (many such publications are already captured in NatureServe's existing summaries). Websites for agencies and NGOs active in the geographic area of interest often contained additional relevant information. The contracting team stays current in much of the published literature relevant to ecosystems, landscape ecology, hydrology and geohydrology, conservation planning, vegetation classification and mapping, fire ecology, and climate change effects on biodiversity. As a result, much of the content development for the MAR ecoregion CEs was focused on finding the more recent publications, whether peer-reviewed papers, federal agency reports, conference proceedings, or NGO reports. In addition, members of the AMT, Technical Team, or other known experts in the CEs were consulted for their knowledge of key recent work and information that is important for the CEs.

Species CEs

In the section that follows, the content included for each species CE is described. Characterization data that has been developed for these species is intended to provide information for the taxon across the entire range of its distribution (i.e., global-level data), and then to provide information that is most relevant to the MAR ecoregion for the species. Initially, species CE data has been obtained from a biodiversity database developed centrally at NatureServe over the past thirty-five years. This database is dynamic, maintained and refined through updates made to reflect current changes to taxonomy, and by the periodic import of new records that are developed according to standard methodology by natural heritage member program scientists and other collaborators, including government agencies, universities, natural history museums and botanical gardens, and additional conservation organizations. This ongoing process of information being added and existing records revised helps to maintain currentness and enhance completeness of the data.

NatureServe's database contains an array of information about elements of biodiversity, with particular emphasis on those that are more threatened across their range. Tracked data includes taxonomy, conservation status, ecological and life history, habitat requirements, and distribution, with primary sources of this information consisting of scientific literature, museum specimen records, reliably documented observation records, species lists, range maps, external databases, and experts, including scientists from natural heritage member programs.

Additional information for each species has been developed for the MAR ecoregion. Much of this has been done through additional literature review by taxonomic experts for the species CEs, who generally stay current with the published literature and data for particular groups of species. State agency websites, which provide and maintain a wealth of information for many species occurring in the state, were also consulted. In addition, members of the AMT, Technical Team, or other known experts in the CEs are consulted for what they know of recent work and information that is important for the CEs.

A.2 From Management Questions to Assessments: Identification, Review, and Synthesis

The narrative below provides more detail on the process used to arrive at the set of assessments that are under consideration for this REA.

MQs proposed in the Development Forums in January 2013 were compiled and organized thematically, both by CA(s) and by conservation element(s). They were compared with MQs selected in completed REAs for nearby ecoregions (Comer et al. 2012a, Comer et al. 2012b, and Strittholt et al. 2012) and reviewed by experts on the contracting team to 1) ensure that regionally significant issues were captured, and 2) preliminarily characterize whether the MQs are expected to be within or outside of the scope of the REA. The contracting team also began documenting the assessments or other sources of information that may be used to address the MQs. Additional input on the MQs was provided during the second AMT workshop in April/May 2013 and by BLM following that workshop.

Following this additional input and direction, the contracting team further reviewed the MQs to 1) revise the characterization of what questions are within the purview of an REA (without budget considerations), and 2) distill the MQs into a brief series of key questions organized by the major thematic areas into which the original MQs had been grouped (e.g., grazing-related questions, border-related questions, climate questions, etc.) that synthesizes the primary questions and issues posed by the numerous individual MQs. These MQ narratives are provided in the relevant subsections ("Management Concerns Around…") of the Current Issues chapter in this report.

The distillation of the 200 MQs into a discrete series of narrative questions for this report serve as the proposed REA assessments that are identified in the REA work plan (Crist et al. 2013). The work plan incorporates summaries of 1) the proposed set of assessments, 2) an approach for determining availability of suitable data and modeling approaches for conducting the proposed assessment, 3) approaches for conducting all of the assessments (both "special" and "standard"), and 4) a process for determining the subset of "special" assessments that can be conducted within REA resources. The work plan and proposed assessments were reviewed by the AMT and Technical Team in a pair of AMT workshops held as webinars in July 2013. This AMT review resulted in an initial prioritization of the "special" assessments. Per the approach outlined in the work plan, following the evaluation of available data and modeling or assessment tools to confirm technical feasibility, the AMT will be engaged to confirm the first set of special assessments that will be initiated; see the finalized work plan (Crist et al. 2013) for more detail.

The original set of detailed MQs identified in the Development Forums are provided in **Appendix B**.

A.3 Conservation Element Identification and Selection

The narrative below provides significantly more detail on the process used to arrive at the final set of conservation elements to be assessed in this REA.

A.3.1 Initial Review and Selection of Three High-Confidence Conservation Elements

As this assessment got underway, the contracting team began reviewing NatureServe's national ecological systems map[5] (Comer et al. 2003, NatureServe 2013), a widely used, nation-wide geospatial data layer of the distribution of ecological systems. The team also began compiling reports from existing, large-scale, natural resources or biodiversity assessments relevant to the ecoregion, including the following assessments:

- Integrated Landscape Assessment Project (ILAP) products for AZ, NM (see http://oregonstate.edu/inr/ilap)
- State Wildlife Action Plans (SWAPs)/Comprehensive Wildlife Strategies (NMDGF 2006, AZGFD 2012)
- BLM's Sonoran Desert REA (Strittholt et al. 2012)
- Apache Highlands ecoregional assessment (a Nature Conservancy-led effort) (Marshall et al. 2004)

The ecological systems and species evaluated in these existing assessments and data sets were reviewed and compiled to develop a list of potential CEs for this REA; these potential CEs were shared in the first AMT workshop in December of 2012. Workshop participants were asked to identify an initial set of three CEs that they were confident were of management interest to major land-owning agencies in the ecoregion and that they were certain would be critical, representative CEs that should assessed in this REA. These initial three CEs included pronghorn (*Antilocarpa americana*), the semi-desert grassland, and the low-elevation riparian/aquatic system. (This early selection of three CEs in the first workshop took place for logistical reasons; the REAs have relatively short timelines and the early selection of three high-confidence CEs was an attempt to ensure the conceptual models for the full set of CEs could be completed within the allotted time frame.)

A.3.2 Development Forum Input

At the end of January 2013, a series of Development Forums were held in BLM offices in Las Cruces, Safford, and Tucson, with both BLM staff and a range of partners participating. In the process of identifying management issues and questions in each of the forums, participants also identified potential CEs of interest (habitat or species). Potential CEs were initially identified from the MQs proposed by participants and summarized in their own lists; participants then suggested additional CEs for consideration, based on the criterion of "regional significance[6]" and other criteria identified by forum participants. Suggested species and habitat CEs were summarized in separate lists in each Development Forum, and participants used "dot voting" to indicate which potential CEs they considered of highest priority for ecoregional assessment. The lists of suggested CEs from each of the Development Forums were then aggregated into two complete lists, one for ecological systems and one for species.

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[5] NatureServe's ecological systems data layer incorporates Southwest Regional Gap Analysis Project (SWReGAP) ecological systems mapping for the five-state SWReGAP region: Arizona, Colorado, Nevada, New Mexico, and Utah. It is also the foundation of the LANDFIRE national vegetation map layer.

[6] In this REA, having relevance to more than one or two BLM field offices or comparable landscape-level distribution; not species that are highly localized.

A.3.3 Initial Compilation of Candidate Conservation Elements

A.3.3.1 Ecological System Conservation Elements

For habitat CEs, the contracting team used NatureServe's classification of ecological systems as a starting point (Comer et al. 2003). This classification was used in the adjacent Sonoran REA and is widely used for vegetation mapping (e.g., LANDFIRE existing vegetation and biophysical settings mapping, Southwest ReGAP vegetation mapping). The ecological system types also link directly or can be cross-walked to many of the types modeled by ILAP. Ecological systems that are mapped within the Madrean Archipelago ecoregion (as shown by the solid green outline in Figure 2-2) formed the initial list of possible ecological system CEs. The list of potential habitat CEs identified in the Development Forums was cross-walked to the list of ecological system types.

Ecological systems that are characteristic of or have their primary range in this ecoregion were recommended as higher priority, while types peripheral to the ecoregion or having the bulk of their range outside the ecoregion were recommended as lower priorities. The areal extent as mapped by SW ReGAP for each ecological system was calculated in both acres and as a percent of the total area of the ecoregion; this was used to identify those ecological systems occupying the largest proportions of the MAR ecoregion. NatureServe's Regional Vegetation Ecologists then reviewed the ecological systems to identify the types having their primary range in this ecoregion or that are characteristic of this ecoregion. These types were identified as the highest priority to consider for inclusion in the assessment. Those that are peripheral or have their primary distribution elsewhere were ranked as lower priority for assessment.

Although small in spatial extent, aquatic, wetland, and riparian ecological systems play a crucial role in this arid ecoregion. Therefore, several ecological systems representing a cross-section of the key aquatic habitats of the ecoregion were included as candidate CEs. These aquatic ecological systems represent an elevational gradient as well as different hydrologic regimes (alluvial ecosystems as opposed to groundwater-fed systems (e.g., springs and seeps), or depressional wetlands (e.g., playas)). All of these aquatic CEs are distributed more widely in the southwestern U.S. than just the Madrean Archipelago ecoregion, but they represent an ecological cross-section of the characteristic hydrologic regimes and faunal/floristic composition found in the MAR ecoregion. In this REA, the aquatic or "wet" component of the habitat is combined with its associated vegetation component (riparian or emergent wetland vegetation) as a single CE (e.g., the North American Warm Desert Riparian Woodland, Shrubland and Stream is treated as a single CE).

For the upland ecological systems, there are many types having very small areal extents within the ecoregion. Most of these are peripheral to the MAR ecoregion; in other words, most of their distribution is outside the MAR ecoregion proper. Those ecological systems with most of their distribution in this ecoregion, regardless of how much area they occupy, were considered to be of higher priority for the MAR assessment. In addition, ecological systems were selected to represent a cross-section of biophysical settings (e.g., elevation and soils), and floristic gradients (e.g., ranging from desert scrub to conifer forests and grasslands). Most of the systems NatureServe identified were also listed in one or more of the development forums. All of the selected ecological systems are important representatives of the MAR ecoregion's range of ecosystem dynamics and varied sky island topography; they represent components of the conceptual model for the MAR ecoregion.

Although it would be preferable to assess the full suite of the ecoregion's ecosystems, project scope, time, and budget did not permit this. Therefore, systems that are lower ranked (because they are peripheral to ecoregion, or have lower representation in this ecoregion, or are of concern primarily to a single management entity (e.g., upper elevation systems for the USFS)), especially those where primary

MQs are answered by another recent assessment, may be incorporated into the assessment by reference to other work, rather than being modeled and assessed specifically in this REA.

Below is a summary of the considerations applied in recommending ecological system CEs:

- **Regional significance**
    - **Relevant to more than one BLM field office or other agency's local management jurisdiction**: CEs should have "regional significance" within the ecoregion – that is, they should be of management interest to more than one BLM field office or comparable natural resource agency jurisdiction; species having a highly localized distribution within the ecoregion are not considered regionally significant
    - **Dominant in the ecoregion**: Ecological systems comprising the majority of the land cover
    - **Broadly represent cross-section of region's diversity** (including range of biophysical settings, floristic or physiognomic gradients, elevational gradients, hydrologic regimes)
    - **Endemism**: Systems found predominantly within this ecoregion
- **Nexus with identified management issues** (e.g., hydrology/water availability concerns; priority for management, such as the semi-desert grasslands)

A.3.3.2 Species Conservation Elements

A key consideration for CE selection is whether the CE is of management or conservation concern. Given that the Madrean Archipelago ecoregion is highly diverse and has a significant number of endemic, rare, or threatened/endangered species, hundreds of species have been identified as being of management or conservation concern (see, for example, the SWAPs or the Apache Highlands ecoregional assessment (Marshall et a. 2004)). The species identified and prioritized in the Development Forum provided an initial list of 60 species suggested as CEs for this REA. However, given the large number of species of management interest found within this ecoregion, it was important to consult additional sources to determine whether other species should be added to the list of candidates. The contracting team consulted the following lists of species of potential management importance to identify additional species that might be appropriate to add to the list of candidate species CEs:

- Arizona Species of Greatest Conservation Need
- New Mexico Species of Greatest Conservation Need (NMDGF 2006)
    - Madrean Archipelago species list in the New Mexico Comprehensive Wildlife Strategy (100+ animal species)
- Arizona BLM Sensitive Species for the state (both verified and hypothetical; 44 species)
- New Mexico sensitive species as listed on NM BLM's website (USFWS listed species and species of concern) for Hidalgo County (53 species)
- The Nature Conservancy's list of target species for the 2004 Apache Highlands ecoregional assessment (223 species chosen as targets out of 560+ species reviewed) (Marshall et al. 2004)

The contracting team then reviewed the Development Forum lists and the species of management concern from the sources listed above, and used expert option to apply the following additional considerations to develop a smaller list of candidate species CEs for review by the AMT and Technical Team:

- **Regional significance**
    - **Relevant to more than one BLM field office or other agency's local management jurisdiction**: CEs should have "regional significance" within the ecoregion – that is, they should be of management interest to more than one BLM field office or comparable natural resource agency

jurisdiction; species having a highly localized distribution within the ecoregion are not considered regionally significant
    - **Broadly represent cross-section of region's diversity**: There is a desire to strike a balance to ensure that the CEs selected aren't weighted too heavily toward either mostly grassland/lowland types or species, nor too heavily toward mostly high-elevation types or species
    - **Endemism**: Species having the bulk (75-100%) of their geographic distribution within this ecoregion were considered if they utilized multiple habitat types (i.e., weren't tightly linked to a single ecological system CE that could serve as a surrogate)
- **Nexus with identified management issues** (e.g., hydrology/water availability concerns; priority for management, such as the semi-desert grasslands): For each CE, we noted whether it is:
    - **Adequately addressed through other assessments**
    - **Impacted or likely to be impacted by CAs**
- **Representation by associated ecological system (habitat) CE**: Species that can be reasonably assumed to be well represented if their associated habitat is adequately managed (i.e., species tightly linked to a single habitat or ecological system CE that could serve as a surrogate) were excluded or considered lower priority for inclusion. Conversely, species that may not be adequately represented by a single system type were considered if they:
    - **Utilize multiple habitat types**
    - **Possess unique characteristics or associations (or life history strategies)** that require an investigation beyond its habitat representation through modeling ecological systems

Given the hundreds of species of management concern, it was not possible within the scope of this REA to review and rank each species individually against each of the criteria and considerations discussed above. In addition, with such a large number of species under consideration, detailed application of those criteria would still result in a list of candidate species that far exceeded the maximum of 20 CEs that will be addressed in this REA. The contracting team's review of the species against the criteria listed above resulted in a list of approximately 65 species, with "Yes," "Maybe," and "No" recommendations for assessment in the REA.

The species identified as candidate CEs were all animals, due to management needs; no plant species were included as CEs. Conceptual models for the ecological systems list dominant or characteristic plant species, and include indicators relating to plant species composition, community structure/physiognomy (e.g., canopy cover, shrub component, bare ground, etc.). In addition, key plant species represented by the community types will be identified, and may serve as important indicators if appropriate.

A.3.4 Finalizing the Conservation Element List

Applying these criteria resulted in approximately 20 candidate ecological system CEs and 65 candidate species CEs. Once the contracting team developed a set of final recommendations, based on the various input and sources described above, a series of webinars and conference calls were held with the AMT and Technical Team to review the candidates and arrive at the final list of 19 CEs:

- A webinar was held with the AMT in late February 2013 to review the prioritized lists developed by the NatureServe team, with the original goal of finalizing the list of 20 CEs. In-depth discussion and input resulted in a voting process during the webinar where participants provided expert judgment on which CEs they thought should **not** be assessed; this was used to attempt to narrow the list of CEs. While this resulted in some narrowing, there was a need to better understand the rationale for these opinions.

- As a follow-up to the webinar, the AMT and Technical Team members were asked in mid-March 2013 to rank each CE on the resulting narrowed list (via a survey using SurveyMonkey) and provide a rationale for the rankings.
- The contracting team compiled the rankings, summarized the averages, and reviewed the rationales provided and provided this information to the Technical Team.
- A conference call was held with the Technical Team in early April 2013 to review the survey results and further narrow the list, based on the AMT input and the original considerations and criteria for CE selection.
- A final call was held with the Technical Team a week later to finalize the remaining species and ecological systems to be the CEs for this REA.
- The BLM project manager circulated the final draft list to the AMT and provided the AMT's confirmation on 19 CEs in late April, prior to the second AMT workshop held at the end of April 2013

Again, given the extremely large number of species of management concern, and the limited number of CEs that could be assessed within the project budget, expert judgment of the AMT and Technical Team members was required to finalize the CE list. Assuming future REAs are limited in the number of CEs that can be addressed, the following suggestions may aid the selection process:

- Consider using ecological system CEs as a coarse-filter, and select an initial set of system CEs that are expected to be adequately representative, from the perspective of the resource management agencies. This would likely result in a more limited set of slots for species CEs.
- The candidate species CEs will still need to be narrowed down through expert judgment. Once an initial, relatively small (i.e., <30) list of candidate CEs is identified (using the same criteria as used in this REA), they should be reviewed against the systems a second time to see which ones are least well-represented by the system CEs.

Appendix B Management Questions (MQs)

Management questions are organized by Group, CA Group, and CE Group. Sources of MQs are as follows: LCDO = compiled by staff at BLM's Las Cruces District Office; LC DF = Development Forum held in Las Cruces, NM; Saff DF = Development Forum held in Safford, AZ; Tuc DF = Development Forum held in Tucson, AZ. All Development Forums were held in January of 2013.

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
151	LCDO	Aquatic Ecosystems	All CAs	Ecosystems - Aquatic	Where are riparian, wetland habitats and what are their current condition and trend?
70	Saff DF	Aquatic Ecosystems	Climate Change, Development (Grazing, Mining)	Ecosystems - Aquatic - Seeps and Springs	What is the ecological status of seeps and springs? Are these systems drying out due to climate change or due to other stressors such as livestock and mining? Or both?
3	LC DF	Aquatic Ecosystems	Development	Ecosystems - Aquatic	Availability of riparian wetland ephemeral habitat is an issue for migratory bird and wildlife, especially in ephemeral playas? What is the impact of increased water pumping/expanded agriculture, especially in NM?
5	LC DF	Aquatic Ecosystems	NA	Ecosystems - Aquatic	What aquatic indicator species are best at showing change in aquatic ecosystems (specifically loss of aquatic habitat, but possibly including water chemistry/quality)?
1	LC DF	Aquatic Ecosystems	NA	Ecosystems - Aquatic - Riparian	What riparian habitat existed historically in the region and which remain? What actions can protect the watersheds and groundwater to maintain and restore riparian habitats?
99	Tuc DF	Biodiversity	NA	All CEs	How does biodiversity within MAR compare to other Arizona ecoregions?
154	LCDO	Biodiversity	NA	Ecosystems	Where are landscapes/unique communities/watersheds with high species richness (both plants and animals) of regional concern? Need to define which of the 3 kinds of species richness would be assessed, since they all have different meanings. G-Ranks and special status are only a component of species richness. Also consider endemism (which goes beyond G-Ranks) – which taxa are limited to the ecoregion or specific HUCs or isolated communities.

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
155	LCDO	Biodiversity	NA	Ecosystems	Where are the landscapes/unique communities/watersheds (5th level HUC) containing G1-G3 plant and animal species? (Note: NM Heritage is currently revamping the G rankings)
150	LCDO	Biodiversity	NA	Ecosystems - Terrestrial	Where are areas with high warm and cool season flowering shrub and herbaceous plant populations and diversity (applies to forage values, pollinator habitat, recreational/botanic values)?
39	LC DF	Climate Change	Climate Change	All CEs	What is the impact of climate shift to wet-cold rather than dry-warm relative to study objectives?
158	LCDO	Climate Change/ CE Distribution	Climate Change	All CEs	Where are climatic zones located today and what are the potential realistic scenarios for climate (precipitation, temperature, evapotranspiration, storm intensity, flood frequency, etc.) and the impacts to regionally significant conservation elements? (i.e. how will bioclimatic changes affect current and potential habitat/species distributions?).
159	LCDO	Climate Change/ CE Distribution	Climate Change	All CEs	What are the predicted changes in distribution of vegetation types and regionally significant conservation elements given climate change?
33	LC DF	Climate Change/ CE Distribution	Climate Change	Ecosystems - Terrestrial	What are the potential changes in the community dominance of grassland and desert scrub as a result of climate change?
71	Saff DF	Climate Change/ CE Distribution	Climate Change	Ecosystems - Terrestrial	How will vegetation communities change/shift with climate change? Specifically grassland areas drying out in climate scenarios. Where could grazing be moved? How could things be implemented to improve stability? Such as prescribed fires in advance, erosion control. Can be used to inform pro-active management options.
119	Tuc DF	Climate Change/ CE Distribution	Climate Change	Ecosystems - Terrestrial	(pine communities going to oak due to projected (drier?) climate)

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
38	LC DF	Climate Change/ CE Distribution	Climate Change	Ecosystems - Terrestrial - Montane woodlands and forests	[What are] potential changes to mid to high elevation woodland vegetation as a result of climate change (lower precip, higher temps) and changes in seasonal precipitation?
121	Tuc DF	Climate Change/ CE Distribution	Climate Change	Species	How many species will be lost from mountain tops due to global warming?
~~144~~	~~Tuc DF~~	Climate Change/ CE Distribution	~~Climate Change~~	~~Species~~	~~How many species will be lost from mountaintops due to global warming?~~
16	LC DF	Climate Change/ CE Distribution	Climate Change	Species - Bats and Plants	How climate change alters the distribution of threatened and endangered bat and plant species? Note: often we are managing toward climax community which may not be the community we want to support T&E species but this may not be suiting our need
160	LCDO	Climate Change/ CEs	Climate Change	All CEs	Where are species habitats/landscapes/unique communities/watersheds most vulnerable to changing climatic conditions?
162	LCDO	Climate Change/ CEs	Climate Change	Ecosystems - Aquatic	Where are watersheds with the greatest potential for thermal and hydrologic alterations [as a result of climate change]?
2	LC DF	Climate Change/ CEs	Climate Change	Ecosystems - Aquatic - Riparian	Which riparian habitats are most at risk due to climate variability?
163	LCDO	Climate Change/ CEs	Climate Change	Ecosystems - Aquatic - Riparian	Where will riparian systems change (i.e. the ratio of perennial vs. ephemeral/intermittent riparian/wetland communities) [in response to climate change]?
35	LC DF	Climate Change/ CEs	Climate Change	Ecosystems - Terrestrial	Where will state and transition models change in response to climate change?
167	LCDO	Climate Change/ CEs	Climate Change	Ecosystems - Terrestrial	Where will state and transition models change in response to changing climatic conditions? And how will this affect identification of landscapes/communities/watersheds with restoration potential?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
106	Tuc DF	Climate Change/ CEs	Climate Change	Species	What are the risks to plants and wildlife from insects and pathogens that expand range into MAR?
117	Tuc DF	Climate Change/ CEs	Climate Change	Species	Are there species that have the majority of their range within MAR (that would then be vulnerable to MAR impacts?)
120	Tuc DF	Climate Change/ CEs	Climate Change	Species	Are there species currently common in MAR that are particularly vulnerable to climate change?
197	Nature Serve	Climate Change/ CEs	Climate Change	Species	What is the degree of vulnerability of species CEs to projected climate change and where will the most vulnerable species CEs experience significant changes in driving climatic variables?
118	Tuc DF	Climate Change/ CEs	Climate Change	Species - Birds	What are the effects of climate change on bird communities (grassland birds, riparian, forest bird groups) distribution, abundances, and vital rates?
36	LC DF	Climate Change/ CEs	Climate Change, Development	Species - Plants	What is the effect of climate change and anthropogenic uses on persistence of special status plant species?
37	LC DF	Climate Change/ CEs	Climate Change, Fire	Ecosystems - Terrestrial - Montane woodlands and forests	How will climate change affect montane forested habitats on sky islands, including precipitation patterns, habitat connectivity, altered fire regimes, and plant migration?
14	LC DF	Climate Change/ Grazing/ Ecosystems	Climate Change	Ecosystems	What is our establishment of proper grazing pressure on this landscape in respect to future climate? We are often trying to go back to a historical community. How do we look to future conditions?
34	LC DF	Climate Change/ Grazing/ Ecosystems	Climate Change, Development (Grazing)	Ecosystems - Terrestrial - Grasslands	What is the current distribution and projected change in grassland distribution due to climate change and other land use practices, including restoration practices, and changes in livestock distribution?
8	LC DF	Climate Change/ Grazing/ Ecosystems	Grazing, Climate Change	Ecosystems	What effects will continued grazing at current levels have on landscapes in light of climate change?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
7	LC DF	Climate Change/ Other CAs/ Ecosystems	All CAs	Ecosystems - Terrestrial - Grasslands	Loss of historical semi-desert grassland community structure and function due to long-term [changes in] growing season [and] livestock grazing [and] lack of growing season rest [from grazing]; lack of growing season rest has decreased critical warm-season grasses (black grama, bluestems, sideoats grama) and shrubs, which have been replaced by increaser species and invasive grasses and shrubs (e.g., three awns, mesquite, creosote)
72	Saff DF	Climate Change/ Social	Climate Change	NA	How has historic climate change affected human occupation of the region? Throughout human occupation of the southwest, climate change is thought to have been a major factor, would like baseline info and how it affected people of the Southwest over time, and how people have adapted.
73	Saff DF	Climate Change/ Social	Climate Change	NA	How will climate change impacts exacerbate environmental justice issues within ecoregion, if any, e.g., natural disasters, livelihoods, etc.
80	Saff DF	Connectivity	NA	Species	What areas need to be conserved/restored to allow wildlife movement? Jaguar, ocelot, pronghorn are main species of concern for "wildlife movement"
148	LCDO	Connectivity	NA	Species	Where are the corridors (open or restricted) needed to maintain connectivity and/or function (within and to other regions)? Proposed "signifcant landscape scale species": a. Mule deer b. Desert bighorn sheep c. Chiricahua leopard frog d. Lesser longnosed bat e. Mexican longnosed bat f. NM ridgenose rattlesnake g. Pronghorn

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
165	LCDO	Connectivity/ Climate Change	Climate Change	Ecosystems	How will climate change influence the connectivity of regionally significant habitats?
108	Tuc DF	Connectivity/ Climate Change	Climate Change, Development	Ecosystems	Fragmentation of habitat and consequences of climate change
79	Saff DF	Connectivity/ Development	Development	Ecosystems - Terrestrial	What will the impacts be to habitat (fragmentation) from the three major, on-going transmission line projects in the ecoregion? Major transmission projects include Sunzia, Southline, and Centennial West. Resulting fragmentation → can't use prescribed fire Transmission lines → issues for raptors??
109	Tuc DF	Connectivity/ Development	Development	Ecosystems - Terrestrial	Are there particular unfragmented/ intact areas within MAR that are vulnerable to energy/resource development?
45	LC DF	Connectivity/ Development	Development	Species - Terrestrial	Fragmentation of movement corridors between mountains and basins as a function of development, land use – in relation to desert bighorn, pronghorn, herptiles [etc]
107	Tuc DF	Connectivity/ Development	Development	Species - Terrestrial	What are the effects of fragmentation (multiple-use) to terrestrial wildlife (linear right-of-ways, fire breaks, canals, roads)
41	LC DF	Connectivity/ Development	Development	Species - Terrestrial - Mule deer	What patch size is necessary to maintain healthy mule deer herds, and how can the transportation system be managed to maintain existing patches and restore lost patches?
110	Tuc DF	Connectivity/ Development	NA	Species	How will stakeholders work together to secure movement corridors for animals and plants?
187	LCDO	Connectivity/ Development/ Border	Development/ Border	Species	How have regionally significant species and habitat connectivity been affected by DHS/CBP activities (i.e. border fence, border roads, tire drag areas, and other infrastructure)?
42	LC DF	Connectivity/ Development/ Border	Development/ Border	Species - Terrestrial - Large mammals	How do border control activities (such as fences, roads, vehicle barriers, and traffic) affect movement of terrestrial mammals (such as pronghorn, mule deer, jaguars?) and will immigration reform improve border habitat connectivity?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
82	Saff DF	Connectivity/ Development/ Border	Development/ Border	Species - Terrestrial - Large mammals	How is large mammal migration impacted by the border fence? The fence has slowed jaguar, mountain lions, all large cats, bears, and deer movement.
112	Tuc DF	Connectivity/ Invasives	Invasives	Ecosystems - Terrestrial - Grasslands	How can we “restore” grasslands fragmented by shrub invasion across multiple jurisdictions?
124	Tuc DF	Connectivity/ Management and Restoration	Development	Species - Terrestrial - Nectar-feeding bats	How will monitoring and structures of wind energy change for nectar feeding bats (in MAR)?
123	Tuc DF	Connectivity/ Management and Restoration	NA	Species	What effects do private riparian/grassland restoration efforts (e.g. Malpai Borderlands, Cuenca los Ojos Foundation) have on increasing the number of perennial reaches and wildlife movement?
125	Tuc DF	Connectivity/ Management and Restoration	NA	Species - Terrestrial - Large mammals	(What are the implications of landscape management for large predators – landscape management and jaguar?)
46	LC DF	Development	Development	All CEs	What are the patterns and impacts of future development, e.g., urban development, restoration, energy development?
182	LCDO	Development	Development	All CEs	Where are existing and potential energy development (oil, gas, mineral, solar, wind, geothermal, biomass, bioenergy, other renewables) and associated infrastructure (roads, ROWs, etc.) and what is their proximity to resources of high conservation and/or restoration potential?
183	LCDO	Development	Development	All CEs	Where is existing agriculture and future potential of land conversion to agriculture (CRP and other conversion through tillage)?
113	Tuc DF	Development	Development	NA	Development: Mining (mining law; protecting areas in relation to mining law)
111	Tuc DF	Development	Development	Species - Birds	What are the effects of development (all types) on bird communities? (e.g. riparian, grassland)

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
189	LCDO	Development/ Border	Development/ Border	All CEs	Other border activities and/or impacts for consideration: Hazardous material sites created by undocumented alien traffic. Impacts to dispersed recreation. Impacts to fire suppression activities and subsequent impacts to vegetative community values.
83	Saff DF	Development/ Border	Development/ Border	Ecosystems - Aquatic	How does other side of border affect water and air quality?
186	LCDO	Development/ Border/ CEs	Development/ Border	All CEs	What and where will regionally significant values be affected by Department of Homeland Security/Customs and Border Protection (DHS/CBP) activities? border fencing border towers new trails/roads other border infrastructure (such as???) abandoned vehicles from undocumented immigrant traffic lay-up sites/dumping/trash/hazardous material sites created by undocumented immigrant traffic effects of undocumented immigrant pedestrian traffic on soil erosion in roadless areas border infrastructure lighting, along fence and towers (bird migration)? border-related fire suppression or fire ignition????

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
81	Saff DF	Development/ Border/ CEs	Development/ Border	Ecosystems	What are the border-related impacts on ecoregion, with regard to water, soils, vegetation, ecosystem functionality? What is impact of border fencing, border towers, new trails/roads, other border infrastructure, abandoned vehicles, lay-up sites/dumping/trash, border infrastructure lighting (bird migration)? (these considerations might be incompatible scale with REA) How does traffic affect the ecosystem? Such as soil surface erosion from traffic, pedestrian and vehicular, on and off road? There is also traffic from smugglers, law enforcement, and recreational use. All this traffic could affect wilderness areas, and soils. Also trash disposal. Look at erodible soils? Look at areas without paved roads Some soils more sensitive to erosion. Some erosion concerns are more slope related, such as trails through mountains can cause erosion. Some areas are more susceptible than others, such as drainage bottoms, and calcic (or limestone) soils ("desert pavement"), which support rare plants).
116	Tuc DF	Development/ Border/ CEs	Development/ Border	Ecosystems	How can "homeland security" activities be guided to have fewer impacts to watershed and ecosystems at and near US/Mexico border?
188	LCDO	Development/ Border/ Other CAs/ CEs	Development/ Border, Other CAs	All CEs	How will direct and indirect impacts of border activity affect habitat or species sensitivity driven by changes in fire regime and/or climate change (i.e., what is the cumulative effect?)?
44	LC DF	Development/ CEs	Development	All CEs	What are impacts on natural resources (soil, water, animals, air, vegetation) of increased roads/transportation systems? (All things considered with roads, transportation system etc. future demands on it from the corridor system.)

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
181	LCDO	Development/ CEs	Development	All CEs	Where will regionally significant values [CEs] be affected through development? Note: land status within the ecoregion may also be a consideration when addressing these change agents. The co-mingled land status has management implications for public land managers.
184	LCDO	Development/ CEs	Development	All CEs	Where are existing population centers (and "sprawl" areas) and what is their proximity to resources of high conservation and/or restoration potential?
185	LCDO	Development/ CEs	Development	All CEs	What level of protection from development is currently in place for regionally significant values (i.e. special land use designations and ownership)?
141	Tuc DF	Development/ CEs	Development	Ecosystems	Recreation (Development): Impacts of ORV use on ecosystems/habitats
47	LC DF	Development/ CEs	Development	Ecosystems - Aquatic - Riparian	What are the impacts of oil shale development on riparian systems?
43	LC DF	Development/ CEs	Development	Ecosystems - Terrestrial	How do power lines and transmission development impact ecosystems?
54	LC DF	Ecological Status/ Biotic Integrity	All CAs	All CEs	Where are landscapes/communities/watersheds with high species richness or biotic integrity, and what are the threats?
157	LCDO	Ecological Status/ Biotic Integrity	All CAs	All CEs	Where are current "at risk" areas (limited connectivity, small size, imminent threat from change agents, introduction of disease and/or disease vectors)?
152	LCDO	Ecological Status/ Biotic Integrity	All CAs	Ecosystems	Where are HUC 5 watersheds with impaired waters and why?
153	LCDO	Ecological Status/ Biotic Integrity	NA	Ecosystems	Where are "at risk" watersheds with regionally significant mechanism that have or can lead to future impairment?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
156	LCDO	Ecological Status/ Biotic Integrity	NA	Ecosystems	Where are landscapes/communities/watersheds with high biotic integrity? Regionally significant landscape/community features: Madrean woodland/forest areas Grasslands/savannahs Lowland riparian/wetlands/playas/ciénegas Upland riparian/wetland
145	LCDO	Ecological Status/ Biotic Integrity	NA	Species	Where and what is the status of the habitat for these significant landscape scale species? Proposed "signifcant landscape scale species": a. Mule deer b. Desert bighorn sheep c. Chiricahua leopard frog d. Lesser longnosed bat e. Mexican longnosed bat f. NM ridgenose rattlesnake g. Pronghorn
133	Tuc DF	Ecosystem Services	NA	Ecosystems	What ecosystem services are provided by different habitats?
172	LCDO	Fire	Fire	Ecosystems	Where are watersheds with both high fire risk and high erosion potential?
131	Tuc DF	Fire	Fire	Ecosystems - Terrestrial	Fuels build up due to “full fire suppression,” resulting in altered fire regime and threatening watershed conditions of flow after fires.
173	LCDO	Fire	Fire	Ecosystems - Terrestrial	Where will the departure from historic and/or current fire regime be most significant?
130	Tuc DF	Fire	Fire	Species - Aquatic - Fish	How do fires affect fish populations (Gila chub, Gila top minnow)

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
129	Tuc DF	Fire	Fire	Species - Birds	What are the effects of fire regime changes on grasslands, riparian and forest bird communities? (Fire history/regime very difficult to characterize in grassland portion) Lack of fire effects to grassland species. Fire regime departure is a landscape-scale metric while the faunal communities are at the stand-scale.
24	LC DF	Fire	Fire, Climate Change	Ecosystems - Terrestrial	Paraphrased: What are the proper reintroduction intervals and sizes for fire as a management tool, given both current and predicted climate?
78	Saff DF	Fire	Fire, Climate Change	Ecosystems - Terrestrial	How will increased ignition sources (human), coupled with precipitation extremes (i.e., none to unseasonal precipitation) affect fire regimes? Increased anthropogenic ignitions are also a border-related issue.
76	Saff DF	Fire	Fire, Invasives	Ecosystems	Wildland urban interface (WUI), invasive species, watershed, fire management direction, fuels treatments These were listed as a group of related issues, not framed as a specific question
21	LC DF	Fire	Fire, Other CAs	Ecosystems - Terrestrial - Woodlands	Which areas are sustaining Madrean woodlands through natural or prescribed fires? Which areas have departed from historical fire regimes? What other change agents besides grazing have resulted in broken fire cycles?
168	LCDO	Fire/ CEs	Fire	All CEs	Where will regionally significant values be at risk from wildland fire?
132	Tuc DF	Fire/ CEs	Fire	CEs - Montane	What happens when you burn a whole sky island? What are consequences (refugia for wildlife species, etc)
171	LCDO	Fire/ CEs	Fire	Ecosystems - Aquatic	Where are areas of high fire risk and what is their connectivity to aquatic systems?
22	LC DF	Fire/ CEs	Fire	Ecosystems - Terrestrial	What is the role of fire across the landscape? How can we restore fire across multiple jurisdictions and ownerships?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
23	LC DF	Fire/ CEs	Fire	Ecosystems - Terrestrial	**What sites respond to fire and how do they respond?** Can fire be used to maintain chemical herbicide treatments?
169	LCDO	Fire/ CEs	Fire	Ecosystems - Terrestrial	Where will the trend (historic to present to future) of wildland fire change (frequency, severity, and seasonality) in the different regionally significant community types (based on fire history, current habitat types/structure, and projected influences of climatic change)?
170	LCDO	Fire/ CEs	Fire	Ecosystems - Terrestrial	How do current fire regimes depart from historic and how has this impacted key regionally significant community types (i.e. habitat for key species; current fire regime may be too long based on historic land use, a departure to a shortened fire regime may be more beneficial to some species)?
200	LC DF	Fire/ CEs	Fire	Ecosystems - Terrestrial	What sites respond to fire and how do they respond? **Can fire be used to maintain chemical herbicide treatments?**
174	LCDO	Fire/ CEs	Fire, Climate Change	Ecosystems - Terrestrial	What is the resiliency of current vegetation communities across the ecoregion to wildfire and how will this resiliency change as a result of changes in climatic conditions?
198	LC DF	Fire/ CEs	Fire, Other CAs	Ecosystems - Terrestrial - Woodlands	Which areas are sustaining Madrean woodlands through natural or prescribed fires? **Which areas have departed from historical fire regimes?** What other change agents besides grazing have resulted in broken fire cycles?
199	LC DF	Fire/ CEs	Fire, Other CAs	Ecosystems - Terrestrial - Woodlands	Which areas are sustaining Madrean woodlands through natural or prescribed fires? Which areas have departed from historical fire regimes? **What other change agents besides grazing have resulted in broken fire cycles?**
175	LCDO	Fire/ Climate Change/ Ecosystems	Fire, Climate Change	Ecosystems - Terrestrial	What vegetation communities have potential to increase or maintain resiliency to changes in fire regime and climate and what types of restoration or management practices would be most effective?
18	LC DF	Fire/ Invasives/ Ecosystems	Fire, Invasives	Ecosystems - Terrestrial	How do invasive grass species such as buffelgrass and cheatgrass affect native fire regimes, intensity, seasonality, and native plant mortality? How can we restore native grasslands and fire regimes?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
74	Saff DF	Grazing	Grazing	Ecosystems - Terrestrial	What is the true carrying capacity (for livestock and wildlife) on BLM grazing allotments? Are the rangelands truly perennial or have some been misclassified and should be ephemeral? What are current assignments of ephemeral vs. perennial for grazing allotments? Are the designations appropriate? Might need perennials to go back to ephemeral in some areas; in other areas, formerly perennial, but so over-grazed, in effect they are ephemeral.
114	Tuc DF	Grazing	Grazing, Invasives	Ecosystems	(spread of invasives; changes in plant communities; changes in watershed function, water budget) (This series of issues was listed in relation to grazing in one of the forums…)
9	LC DF	Grazing/ Biodiversity	Grazing	All CEs	Are current grazing levels impacting species richness/diversity?
11	LC DF	Grazing/ CEs	Grazing	Ecosystems - Terrestrial - Grasslands	Loss of remaining intact grassland as a function of new technology and changing livestock distribution? Where are intact grasslands and where is loss happening now as a result of new technology/changing livestock distribution? Where might it happen in future? [New technologies for accessing water for livestock, such as solar water pumps, high pressure pipes, etc. on federal, state, and private lands, have permitted grasslands that were formerly not possible to be grazed due to lack of water to now be grazed]
15	LC DF	Grazing/ CEs	Grazing	Species	Where and how are livestock management practices impacting habitats for key landscape wildlife species?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
12	LC DF	Grazing/ CEs	Grazing, Climate Change, Invasives	Ecosystems	In areas with limited restoration potential, how will grazing impact communities with climate change? E.g. areas that are invaded by native shrubs, are a big source of dust, we continue to graze them and as we get hotter/drier, how will this impact ecological and community health?
10	LC DF	Grazing/ CEs	Grazing, Invasives	Ecosystems - Terrestrial - Grasslands	How has the lack of growing season rest contributed to decreased critical warm season grasses with invasive species?
13	LC DF	Grazing/ Restoration	Grazing	Ecosystems	After 50 years of grazing, for sites that are completely type converted, what are the thresholds for soil erosion/site capabilities? Note: highly degraded areas that are not prioritized for restoration, potentially problematic, what do we do with them?
179	LCDO	Invasives	Invasives	All CEs	What are the regionally significant invasive species: Buffelgrass Lehmann's love grass Tamarisk Cheatgrass, red brome Yellow star thistle African rue Chytrid fungus Crayfish Bullfrog Feral hogs
180	LCDO	Invasives	Invasives	All CEs	What is the composition and spatial distribution of invasive species?
176	LCDO	Invasives	Invasives	Ecosystems	Where will landscapes/communities/watersheds most likely be affected by changes in the spatial distribution and abundance of invasive species due to change agents (climate change, wildland fire, anthropogenic disturbances)?
177	LCDO	Invasives	Invasives	Ecosystems	How will the potential for establishment of invasive species change over time in response to changes in climate and fire regimes?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
104	Tuc DF	Invasives	Invasives	Ecosystems - Aquatic	How will invasive aquatic species be controlled?
100	Tuc DF	Invasives	Invasives	Ecosystems - Terrestrial	Buffelgrass planting in Mexico
101	Tuc DF	Invasives	Invasives	Ecosystems - Terrestrial	(invasive invertebrates – e.g., beetle species coming from Mexico)
102	Tuc DF	Invasives	Invasives	Ecosystems - Terrestrial - Grasslands	What strategies can be used to minimize spread and detect new invasive grassland species? Currently no management strategies exist to control certain exotic grasses (e.g., Lehmann Lovegrass) that affect semi-desert grasslands.
178	LCDO	Invasives/ Climate Change	Invasives, Climate Change	Ecosystems	Will native invasive species (mesquite, creosote bush, etc.) become more dominant within ecological site descriptions as a result of climate change?
17	LC DF	Invasives/ Climate Change	Invasives, Climate Change	Ecosystems - Terrestrial	What is the projected expansion of invasive woody species as well as riparian vegetation and woodlands with elevated carbon dioxide levels as a result of climate change or anthropogenic activities?
103	Tuc DF	Invasives/ Grazing/ Climate Change/ Development	Grazing, Invasives, Development, Climate Change	Ecosystems	Range and livestock management – Grazing can spread exotic or native invasive species, change plant communities and affect watershed function. How will climate change / development affect this land use (grazing) and consequently the CEs?
19	LC DF	Invasives/ Terrestrial Ecosystems	Invasives	Ecosystems - Terrestrial - Grasslands	Where are intact grasslands going to be most threatened by invasive species in the mid and long term?
20	LC DF	Invasives/ Terrestrial Ecosystems	Invasives	Ecosystems - Terrestrial - Grasslands	What exotic species, that could have a detrimental impact on native grasslands, could reasonably be expected to become established and how would they affect native grasslands? How can we prevent establishment or control them?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
147	LCDO	Landscape Species	All CAs	Species	Where are the current at risk areas for each species (limited connectivity, small size, imminent threat from change agents, introduction of disease and/or disease vectors)? Proposed "signifcant landscape scale species": a. Mule deer b. Desert bighorn sheep c. Chiricahua leopard frog d. Lesser longnosed bat e. Mexican longnosed bat f. NM ridgenose rattlesnake g. Pronghorn
146	LCDO	Landscape Species	NA	All CEs	Or, taking a different approach….First, where are the unique habitats or communities in the Madrean Ecoregion (current, potential, and priority)? Then, are there key indicator and/or endemic species for these unique communities that are sensitive to ecosystem instability or change?
149	LCDO	Landscape Species	NA	Species	Where are the potential restoration areas to improve conditions for the species or restore connectivity and/or function? Proposed "signifcant landscape scale species": a. Mule deer b. Desert bighorn sheep c. Chiricahua leopard frog d. Lesser longnosed bat e. Mexican longnosed bat f. NM ridgenose rattlesnake g. Pronghorn
134	Tuc DF	Law: Water and Mining	Development	All CEs	How does mining law affect our ability to protect resources and how do we protect those resources in the future?
135	Tuc DF	Law: Water and Mining	Development	All CEs	What aspects of water/mining laws restrict/constrain land managers' abilities to conserve habitat and wildlife diversity?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
136	Tuc DF	Law: Water and Mining	Development	All CEs	How do differences in mining, wildlife and water management law affect habitat and population health?
143	Tuc DF	Law: Water and Mining	Development	All CEs	How do differences in mining/wildlife/water management/law in US and Mexico affect habitat and population health?
97	Tuc DF	Law: Water and Mining	Development	Water	(water law – lack of understanding of connection between ground and surface water – dual law; water rights and in-stream flow)
193	LCDO	Management and Restoration	All CAs	NA	What is the projected level of sustainability of restoration efforts given the potential effects of other change agents?
50	LC DF	Management and Restoration	Climate Change	All CEs	What species, taxa, or communities would require management actions such as restoration, ex situ measures, or assisted migration as a result of climate change and anthropogenic changes, including changes resulting from current restoration practices?
191	LCDO	Management and Restoration	Climate Change, Fire	Ecosystems	What is the impact of restoration efforts to landscape function and overall resiliency from predictive changes in climate and/or wildland fire?
194	LCDO	Management and Restoration	Climate Change, Fire	Ecosystems	What is the probability of success for restoring ecological function at the ecoregional scale (also considering multiple scales) under the current restoration approach/techniques/capabilities and predictive changes in climate and/or wildland fire?
77	Saff DF	Management and Restoration	Fire	Ecosystems - Terrestrial	Landscape scale vegetation management This was listed as an issue relating to fire, not framed as a specific question
49	LC DF	Management and Restoration	Fire	Ecosystems - Terrestrial - Grasslands	Where are our priority regions that have the most potential for positive response to our Restore initiative (chemical treatment followed by fire)? This is primarily in relation to grasslands
53	LC DF	Management and Restoration	Invasives	All CEs	Inadequate coordination of invasive species management [across ownerships, jurisdictions]

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
190	LCDO	Management and Restoration	NA	Ecosystems	Where have landscape scale restoration activities been implemented within the ecoregion?
192	LCDO	Management and Restoration	NA	Ecosystems	What is the impact of restoration efforts to species richness?
195	LCDO	Management and Restoration	NA	Ecosystems	What are factors that would limit restoration potential and/or put current or future restoration efforts "at risk" of success?
48	LC DF	Management and Restoration	NA	Ecosystems - Terrestrial	What plant species or species ecotypes are needed for restoration projects in other ecoregions for near and long term?
55	LC DF	Management and Restoration	NA	Species	Plant and animal diversity – what's the appropriate scale of impact analysis…as relates to herbicide treatments?
127	Tuc DF	Management and Restoration	NA	Species	Is there a place in the future for species that were previously extirpated (big river fishes in San Pedro, grizzly bears, etc)?
128	Tuc DF	Management and Restoration	NA	Species	How do we restore keystone species (e.g. beaver, bat, prairie dog) while resolving conflicting (single species – e.g. Gila chub, Chiricahua leopard frog, native fish/frogs) management goals.
40	LC DF	Management and Restoration/ Climate Change	Climate Change	All CEs	What adaptation strategies or other responses could work in response to climate change?
166	LCDO	Management and Restoration/ Climate Change	Climate Change	All CEs	What species/taxa or communities will require management actions such as ex-situ measures, assisted migration?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
142	Tuc DF	Management and Restoration/ Climate Change	Climate Change	CEs - Montane	How are we going to deal with mountain top extinction (spruce fir, Chiricahua squirrel, mixed conifer, box squirrel)
52	LC DF	Management and Restoration/ Climate Change	Climate Change	Ecosystems	What are areas of high potential for carbon sequestration?
122	Tuc DF	Management and Restoration/ Climate Change	Climate Change	Ecosystems	Based on climate projections, how effective will our vegetation treatments (e.g. mesquite reduction) be, and should we plan to continue?
126	Tuc DF	Management and Restoration/ Climate Change	Climate Change	Ecosystems	How can we plan for simplification of ecosystems due to loss of species, habitats, and climate change?
161	LCDO	Management and Restoration/ Climate Change	Climate Change	Ecosystems	Where are watersheds with greatest potential for carbon sequestration?
196	LCDO	Management and Restoration/ Climate Change	Climate Change	Ecosystems - Terrestrial	Considering potential changes to vegetation communities as a result of climatic change, where are the areas with the highest restoration potential? (i.e. intact grasslands that will transition to shrub invaded vs. shrub invaded grasslands that will transition to shrub dominated)
51	LC DF	Management and Restoration/ Climate Change	Invasives, Climate Change	Species	Can we use predicted climate change to manage exotic species?
84	Saff DF	Other	Development	Ecosystems	What are the best locations for large-scale land use authorizations (e.g., energy projects)?
137	Tuc DF	Other	NA	Ecosystems	How can historical documents be used to determine what ecosystem processes have been disrupted?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
138	Tuc DF	Other	NA	Ecosystems	How can we use historical documents to assist in formulating Desired Future Condition (DFC) goals?
56	LC DF	Other	NA	NA	Should we classify a risk to 3 stages, so management can see exactly where they stand?
57	LC DF	Other	NA	Species	What is the ecological value of species that we need to preserve, which we then have to kill later (e.g., salt cedar)?
115	Tuc DF	Other/ Air Quality	Climate Change, Development	NA	How will air quality be affected by changes in development and climate change? (type and timing of pollens; amount of dust in air)
105	Tuc DF	Other/ Human Context and Climate Change	Climate Change	NA	Changing human population centers in Mexico and consequent human health issues
75	Saff DF	Other/ Multiple uses/ recreation (as change agents)	NA	NA	What about socio-economic considerations? If socio-economic considerations were incorporated in NEPA some/many projects might not happen. This was a side comment in forum; it was not framed as a specific question (nor posted as a specific issue to address).
25	LC DF	Other/ Productivity/ All CAs	All CAs	Ecosystems - Terrestrial	Decline in net primary ecosystem productivity and diversity (from all change agents)?
28	LC DF	Soils	NA	Ecosystems - Terrestrial	What is the depth of soil moisture and effective soil moisture regime?
32	LC DF	Soils	NA	Ecosystems - Terrestrial	Soil parent materials and land productivity (e.g., clayey soils as product of acidic rocks vs. clayey soils formed by different rock types)
30	LC DF	Soils/ CEs	NA	Ecosystems - Aquatic	Paraphrased: Where or how are erosion and sedimentation adding to [how do they “add to”?] or changing ecosystems? [in riparian/aquatic ecosystems, primarily?? Playas as well? Erosion in grasslands, too?]
31	LC DF	Soils/ CEs	NA	Species	Effect of soil-landscape position, soil depth on plant and animal species

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
26	LC DF	Soils/ Development	Development	Ecosystems	What is the current degree of erosion vs. the altered degrees of erosion under different management practices? Note: more concerned with erosion resulting from development than grazing, particularly corridor development (e.g., pipelines, fences, linear ROWs)
98	Tuc DF	Soils/ Development/ Grazing	Development	Ecosystems	Where are soils most vulnerable to erosion due to agriculture, mining, development, grazing, border?
29	LC DF	Soils/ Development/ Grazing	Grazing, Development	Ecosystems - Terrestrial and Species - Small mammals and reptiles	Is there a threshold for soil disturbance, that results from grazing or grazing infrastructure or linear rights-of-way, that we should be aware of in order to protect small mammal and reptile populations?
27	LC DF	Soils/ Grazing	Grazing	Ecosystems - Terrestrial - Grasslands	Where is soil degradation [due to grazing?] significant enough to prevent a positive response from grassland restoration?
89	Tuc DF	Water	Development	Water	How will changes in water availability affect development trends and patterns?
92	Tuc DF	Water	Development, Grazing	Water	(water flow and “landscape” (development a landscape); retention basins; stock ponds)
94	Tuc DF	Water	Development, Grazing, Climate Change	Ecosystems	Increased erosion, decreased watershed conditions, over sedimentation of riverine water courses due to urbanization, range over-utilization, etc (including climate change)
67	Saff DF	Water	NA	Water	What is the availability of water, both natural and manmade? [NM has inventoried all stock ponds and other water bodies, AZ has not.]
164	LCDO	Water/ Climate Change	Climate Change	Ecosystems - Aquatic	How will surface water availability change (i.e. where are the areas with highest potential for change) [in response to climate change]?
4	LC DF	Water/ Climate Change/ Other CAs	Climate Change, Other CAs	Water	What are the impacts on surface and groundwater availability from climate change, development, or other stressors?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
6	LC DF	Water/ Climate Change/ Other CAs	Climate Change, Other CAs	Water	What is the current projected water balance between groundwater recharge and water pumping? What is the current and projected availability of water for all uses (wildlife, human, livestock, and hydraulic function)?
69	Saff DF	Water/ Development/ CEs	Development	Ecosystems - Aquatic	What is condition of water resources? What anthropogenic uses are competing for water resources?
63	Saff DF	Water/ Hydrology	NA	Ecosystems - Aquatic	What are changes in hydrology historically from 1600 AD on? In US the water levels are changing, going down. There are big differences in the last 100 years. There are changes in hydrology from 1600 AD on, if we can get baseline and determine how it's changed that would be helpful.
96	Tuc DF	Water/ Hydrology/ CAs	Climate Change, Development	Water	What are the effects of changes in run-off and peak flows (due to climate change and development) on channel geomorphology and man-made infrastructure?
90	Tuc DF	Water/ Hydrology/ CAs	Climate Change, Development, Fire	Ecosystems - Aquatic	How will ground and surface water interactions change with fire, development, climate? (riparian/aquatic ecosystems)
65	Saff DF	Water/ Hydrology/ CAs	Development	Ecosystems - Aquatic	What are overall changes in hydrology caused by farm fields, anthropogenic development, upstream stressors (lots of sediment)?
58	Saff DF	Water/ Hydrology/ CEs	Climate Change, Development	CEs - Aquatic	How will abundance of surface water change with climate and development, and the associated vegetative and wildlife communities? Towns/water allocations Groundwater pumping Diversion dams on Gila Riparian systems, springs Fish becoming endangered More contact with invasive species

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
62	Saff DF	Water/ Hydrology/ CEs	Climate Change, Development	CEs - Aquatic	What will result be of increased pressure for water development to meet needs due to increase population and climate change?
87	Tuc DF	Water/ Hydrology/ CEs	Climate Change, Development	Ecosystems - Aquatic - Riparian	How will potential changes in water quality and quantity affect riparian ecosystems?
60	Saff DF	Water/ Hydrology/ CEs	Development	CEs - Aquatic	There are not only pressures on Bonita Creek. The City of Safford is also looking to drill wells on BLM land to supplement water supply in community. City is looking to take full allotment out of Bonita Creek and other wells that could impact other resources as well.
68	Saff DF	Water/ Hydrology/ CEs	Development	CEs - Aquatic	What are the significant anthropogenic water uses (e.g., residential, industrial, agricultural) and what is the impact of these uses on CEs?
61	Saff DF	Water/ Hydrology/ CEs	Development	Ecosystems - Aquatic	How does extracting groundwater affect habitats?
91	Tuc DF	Water/ Hydrology/ CEs	Development	Ecosystems - Aquatic	Groundwater depletion by development and agriculture and mining in southeastern AZ – resulting in decreased and depleted stream flow.
93	Tuc DF	Water/ Hydrology/ CEs	Development	Ecosystems - Aquatic	What impacts will the creation of artificial surface water habitats (e.g. stock waters as fish/frog refugia) have on natural aquatic systems, given the relationship between surface water and groundwater?
139	Tuc DF	Water/ Hydrology/ CEs	Development	Ecosystems - Aquatic	How will watershed health, development, and groundwater resources be managed to protect aquatic habitat?
86	Tuc DF	Water/ Hydrology/ CEs	Development	Ecosystems - Aquatic and Species - Terrestrial	What are the impacts of loss of surface water from groundwater pumping, and effects to terrestrial wildlife?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
59	Saff DF	Water/ Hydrology/ CEs	Development, Invasives	Species - Aquatic	There's continued development and bans on the Gila River, almost all fish are endangered or on the verge of becoming endangered. What are future predictions as habitats shrink and they [fish] are forced into contact with invasive species? If, like now, 80-90% are dependent on riparian areas, so what happens when they [riparian areas] diminish? For example Bonita Creek. City doesn't take it all now but if they did it would impact the water supply for multiple species.
66	Saff DF	Water/ Hydrology/ CEs	Grazing	Ecosystems - Aquatic	Landscape-level watershed degradation/historic livestock How has historical livestock grazing and woodcutting affected hydrology, landscape level watershed degradation, channel geomorphology, and what is the effect on aquatic and riparian systems?
64	Saff DF	Water/ Hydrology/ CEs	NA	Ecosystems - Aquatic	**How have aquatic systems changed from pre-European levels?** Has the Gila River down cut from pre-European level and if so is the current hydrological regime able to support goals in our management plans? For example, mesquite bosques are affected because river is cut below their level, so if old mesquites don't have toes in water we can't do anything about it, but if they still do and can be helped, then we can and should do something about it.
85	Tuc DF	Water/ Hydrology/ CEs	NA	Ecosystems - Aquatic	How will surface water (aquatic habitat) be sustained over time?
88	Tuc DF	Water/ Hydrology/ CEs	NA	Ecosystems - Aquatic	What strategies will be most effective in trying to maintain surface flows in springs and streams?
140	Tuc DF	Water/ Hydrology/ CEs	NA	Ecosystems - Aquatic	What hydrologic processes have been lost with the extirpation of beaver populations?

MQ #	Source of MQ	Group	CA Group	CE Group	Proposed Management Question
201	Saff DF	Water/ Hydrology/ CEs	NA	Ecosystems - Aquatic	How have aquatic systems changed from pre-European levels? **Has the Gila River down cut from pre-European level and if so is the current hydrological regime able to support goals in our management plans?** For example, mesquite bosques are affected because river is cut below their level, so if old mesquites don't have toes in water we can't do anything about it, but if they still do and can be helped, then we can and should do something about it.
95	Tuc DF	Water/ Hydrology/ CEs	NA	Ecosystems - Both - Montane	How important is snow pack to supporting mountain forest and riparian habitat?

Appendix C Ecological System Conceptual Models

Appendix D Species and Species Assemblage Conceptual Models

Appendix E Mesquite Upland Scrub Conceptual Model

Due to the size of the conceptual model appendices, they are provided as separate documents accompanying this report.

Appendix F Other Non-Native Species

Many of the non-natives in the southwestern United States and northwestern Mexico are from Africa, southeastern Asia, Australia or some combination of them, including most of the perennial grasses, athel (*Tamarix aphylla*), and salt cedar (*T. chinensis*; Van Devender et al. 2010). Other non-natives are of European or Mediterranean European-North African origins, notably the winter-spring annual mustards, bindweed (*Convolvulus arvensis*), and star-thistles (*Centaurea* spp.). Some non-natives are of tropical New World origins from Mexico and the Caribbean to South America, including Mexican palo verde (*Parkinsonia aculeata*), tree tobacco (*Nicotiana glauca*), a few annual grasses (*Bromus catharticus, Setaria setosa*), giant salvinia (*Salvinia molesta*), and water hyacinth (*Eichhornia crassipes*). Texas mesquite (*Prosopis glandulosa* var. *glandulosa*) is native to Texas and the American Bullfrog (*Lithobates catesbeianus*) is native to the southeastern United States.

A total of 38 non-native species were preliminarily identified to be of concern as invasive species in the MAR ecoregion. Additional species that were identified but not summarized in the main body of report because a preliminary review suggested they may be of somewhat lesser concern are described here. These additional species are either not easily controlled or managed, are game species, or are of concern in other parts of the United States or Mexico but are not yet established in this ecoregion.

F.1 Other Non-Natives Present in the MAR Ecoregion

The following non-native species are found in the MAR ecoregion, but are unlikely to spread under future climates. Some species are mostly found in more northern or western areas with greater winter precipitation and dry, warm summers. Reduced winter precipitation should inhibit range expansions of arugula (*Eruca vesicaria* ssp. *sativa*), camelthorn (*Alhagi maurorum*), Malta star-thistle (*Centaurea melitensis*), red brome (*B. rubens*), and Sahara mustard (*Brassica tournefortii*). Cheatgrass (*Bromus tectorum*) and red brome are especially vulnerable to winter drought because the seeds only survive in the soil for a few years. Responses to climate changes are more difficult to predict for cheatgrass and yellow star-thistle (*Centaurea solstitialis*) because they have also been collected in the summer rainy season. Cheatgrass has moved into high elevation habitats (see below) in the MAR ecoregion, where it grows in May-June, the high-elevation spring.

Giant reed (*Arundo donax*) is not common in the MAR ecoregion, but is very large and severely impacts aquatic habitats when present. **Brazilian elodea** (*Egeria densa*) and **Eurasian water milfoil** (*Myriophyllum spicatum*) are aquatic herbs that are invasive and found in livestock ponds and tanks; their seeds are presumed to be bird-dispersed.

Arugula escaped from cultivation in 1960s in the Gila Bend area. Today it is a serious invader in Sonoran desertscrub in the Gila Bend-Sentinel area in Maricopa County, Arizona. In the spring of 2005, it was the most abundant annual for 43 mi (70 km) along Interstate 8 westward from Gila Bend. There are a few records in the MAR area near Tucson, but in Sonora, it is moving east along MEX 2 east of Agua Prieta into higher, colder desert grassland (to 4,070 ft (1,240 m) elevation). It is also common to the east in agricultural fields near Janos, Chihuahua. Reduced winter precipitation would probably inhibit expansion in the MAR ecoregion, but it has not yet reached its ecological potential in higher, colder areas.

Malta star-thistle is an Old World annual that is mostly reproductive in spring (March-June) but occasionally in September. It is common on roadsides in the Tucson area, but uncommon elsewhere in the MAR ecoregion.

Sahara mustard is an extreme invasive at low elevations in Lower Colorado River Valley Sonoran desertscrub in southwestern Arizona and southeastern California (Dimmitt and Van Devender 2009). In wet winters, it densely covers sandy flats and dunes at the expense of the diverse native annuals. But it has moved into Arizona Upland Sonoran desertscrub and desert grassland in the Tucson area. It is also moving along MEX 2 into higher, colder desert grassland to 4250 ft (1295 m) elevation east of Agua Prieta, Sonora. It also occurs on roadsides in the El Paso, Texas area at ca. 3900 ft (1190 m) elevation. With decreased winter precipitation eastward expansion would be inhibited, but it has not yet reached its ecological potential in higher, colder areas.

Cheatgrass is present in oak woodland on Baboquivari Peak and in Sycamore Canyon in the MAR. Cheatgrass (*Bromus tectorum)* can invade native grassland communities and displace native plants and thrives in disturbed areas. It can also alter the natural fire pattern when it becomes dense and it can out-compete natives post-fire. Its expansion in lowlands in the Madrean Archipelago ecoregion may be limited by warmer, drier winters.

This is in contrast to the Mohave Desert to the north, where cheatgrass is a serious winter-spring invasive and fire hazard in desertscrub. In the Madrean area it is basically replaced by red brome at low elevations. In recent years, cheatgrass has become established at higher elevations in pine forest and mixed-conifer forest in the Santa Catalina and Rincon Mountains (see below), displacing native species, but not especially a fire hazard.

Athel was long thought to be sterile (Kearney and Peebles 1964) and in the past was commonly used as shade trees near houses and windbreaks in agricultural fields. Recently, it was discovered that in some areas, including the Lake Mead area, Greene Wash north of Tucson, and many areas in southern Sonora and Baja California Sur, that can be reproductive and actively spread in roadside ditches and riparian habitats. It is widespread in the MAR ecoregion, but many records are near old homesteads. This tree needs to be monitored to see if it becomes more reproductive and invasive in the future.

Orchard grass (*Dactylis glomerata*) is a perennial grass native to north Africa and Eurasia. It is a long-established member of the high-elevation meadow flora in the Graham, Huachuca, and Santa Catalina Mountains in the MAR. It is likely to expand in the future, but is a minimal threat to the pine-oak forest ecosystem.

Water-cress (*Nasturtium officinale*) is widespread in permanent stream habitats in the MAR ecoregion in Arizona and northern Sonora. Parrot-feather (*Myriophyllum aquaticum*) and curly leaf pondweed (*Potamogeton crispus*) are aquatic herbs that are in a few MAR ponds.

Africanized honeybee (*Apis mellifera* ssp. *scutellata*) and **European starling** (*Sturnus vulgaris*) are widely introduced in the MAR ecoregion. These species are probably difficult to control and are not serious ecological threats.

The **Eurasian collared-dove** (*Streptopelia decaocto*) was introduced into Florida in 1982, and rapidly spread across the continent to California. It is closely tied to human developments, but easily disperses between them. It only occasionally is seen in natural habitats. It is apparently not displacing native species as yet.

Chytridiomycosis (*Batrachochytrium dendrobatidis*) is a fungal skin disease that is killing amphibians (mostly anurans) around the globe. Ranid frogs and canyon treefrogs (*Hyla arenicolor*) in the MAR ecoregion are infected, but it is very difficult to control. Chytridiomycosis was documented in the Chiricahua leopard frog as early as 1992 (Santo-Barrera et al. 2004). Infected populations may exhibit periodic die-offs or be extirpated, but the Chiricahua leopard frog is persisting with the disease (USFWS

2007). The fungus could be more of a stressor or spread into new aquatic habitats with warmer, drier climates.

F.2 Managed Non-Natives

Brown Trout (*Salmo trutta*) is a prized sport fish that is widely stocked in high-elevation streams and rivers in the western United States. It is very competitive and occasionally hybridizes with native trout. In the MAR ecoregion, it was introduced into upper Lemmon Creek in the Santa Catalina Mountains, and in Frye Mesa Reservoir in the Graham Mountains. It is recognized as one of the 100 “World's Worst” invaders (Global Invasive Species Database).

F.3 Invasive Non-Natives Not Yet Present in the MAR Ecoregion

A number of non-native species are not yet established in the MAR ecoregion, but are very serious invasives or pathogens in other parts of the United States and northern Mexico and have the potential to expand their distribution into the Madrean Archipelago ecoregion. They are the Madrean bark beetle (*Dendroctonus rhizophagus*), red imported fire ant (*Solenopsis invicta*), cactus moth (*Cactoblastis cactorum*), Asian tiger mosquito (*Aedes albopictus*), and the white-nose bat fungus (white-nose syndrome) (*Geomyces destructans*).

The Madrean bark beetle (*Dendroctonus rhizophagus*) is endemic to the Sierra Madre Occidental as far north as the Sierra Huachinera in western Chihuahua and eastern Sonora. It attacks seedling pines in several species, including Apache pine (*Pinus arizonica*) and southwestern white pine (*P. strobiformis*). There is great concern about expansion of its range northward with global warming (Smith et al. 2013). However, it is apparently limited by maximum summer temperatures (Mendoza et al. 2011), and warmer temperatures may not favor its northward expansion into the Sky Island Mountain ranges in northeastern Sonora and southeastern Arizona.

Red imported fire ant (RIFA) (*Solenopsis invicta*) is an invasive species native to South America that arrived in the southern United States in the 1930s. Today it occurs in 13 states in the United States, including local areas in California and New Mexico. RIFA is a regulated species in Arizona, and the Arizona Department of Agriculture surveys high-risk sites such as nurseries, parks, truck stops, golf courses, etc. A colony established near Yuma was eradicated. RIFA lives in humid environments from central Texas throughout the southeastern United States. The Arizona portion of the MAR ecoregion may be too dry for massive invasions, but RIFA could potentially establish in mesic urban habitats.

The **cactus moth** is a South American species whose larvae cause extensive damage to prickly-pear cacti (*Opuntia* spp). It is a serious invasive in the southeastern United States from Florida to Louisiana. It is likely that humidity is too low in the MAR ecoregion for a serious invasion.

White-nose syndrome is a serious disease in bats in northeastern United States south to Alabama and west to Missouri. The disease is caused by the cold-loving fungus (*Geomyces destructans*), which thrives in low temperature and high humidity conditions where bats hibernate. There are concerns about the spread of white-nose syndrome to other parts of the United States.